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NAVAL POSTGRADUATE SCHOOL
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NEEDS AND CHALLENGES

IN

EDUCATION FOR AIRCRAFT DESIGN

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ABSTRACT:

A brief review of recent developments in engineering education leads to basic reflections about the importance of design education. Aircraft design is singled out as a field where demands on design are particularly high and urgent. Basic needs are determined. Additional challenges posed by engineering technology, continuing studies, liberal-technical education, and new concepts of professionalism are discussed. An overall perspective is developed which foresees a dynamic evolutionary process and indicates that much initiative should originate on the faculty level while guidance should be provided on a policy-making level.

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PREFACE AND ACKNOWLEDGMENTS

Qualitative considerations are never quite free from individual disposition and outlook, and particularly a treatise in the field of engineering education should indicate the bent of the investigator's background. Hopefully, the present report reflects the background of having been first in structural engineering in the aircraft industry for almost two decades, then on the aeronautics faculty of the Naval Postgraduate School for about the same length of time, and finally having reached the somewhat detached viewpoint of an emeritus.

The report is based on a good many visits with aerospace companies and universities which were made possible in part by the support from the Naval Air Systems Command under the cognizance of the Structures Administrator. All the individuals who were contacted -- too many to be listed here -- gave generously of their time to discuss various aspects of design education and their own experience and ideas. Special thanks are due to Professors T. H. Gawain, M. B. Kline, and T. Sarpkaya of the Naval Postgraduate School, Professor H. O. Fuchs of Stanford University, and Mr. J. E. Fischler of the Douglas Company at Long Beach whose diverse outlooks and helpful suggestions influenced the final form of this report.

1. PROBLEM STATEMENT AND OBJECTIVE

Questions about education in aircraft design have been raised recently with particular fervor. As a background we should realize that the aircraft designer has enjoyed a high reputation for technical competence and that his education has served as the foundation of outstanding developments. Yet a proud sense of accomplishment is closely coupled with some gnawing doubts about basic educational problems, dangers of overspecialization and detachment from industrial practice. Besides, some basic uncertainties exist regarding the functions of design in engineering and also about the responsibilities of scientists, engineers, and managers.

It appears that a great many considerations can be boiled down to a very basic question: How can the student combine an understanding of scientific theories with an awareness of real-life complexities ? This is the fundamental problem which has to be faced in engineering education in general and particularly in education for aircraft design.

The objective of this report is to establish basic needs regarding education in aircraft design in the United States. This requires coordination of many diverse aspects and includes the following steps:

clarify the situation as it presently exists in aircraft design;

identify the corresponding educational problems;

provide a perspective for recent developments;

and determine basic needs and challenges.

The report is aimed at aerospace faculties and aerospace engineers who are concerned about basic aspects of aircraft design. Faculty members as well as engineers in industry seldom find the time to peruse the general literature outside their special fields of interest. This makes it difficult for them to form well-balanced conclusions on newly developing general trends, particularly at the present time as a new phase in engineering education is evolving. Many things are taking place in diverse fields and the view of the forest may easily be hidden by the trees.

In addition to the basic problem of doing justice to the subject matter, there exists a very real problem of communication. Engineers and engineering educators are used to quantitative thinking. Educational needs, however, are concerned with qualitative considerations of great diversity and a very wide field has to be explored on a verbal level. The corresponding details might tax the patience of the reader who is mainly concerned with grasping the main line of thought and seeing the conclusions.

For this reason as well as in the general interest of clarity and conciseness, all the supporting evidence will be relegated to

appendices. The main body of the report establishes basic considerations in Sections 2 and 3 and presents the principal findings and conclusions in Sections 6 and 7. Sections 4 and 5 provide a "very quick guided tour" -- summarizing only the highlights of recent developments and the fundamental aspects of the present situation, referring to the appendices for further details. It must be borne in mind that these appendices contain the essential substance of the report.

As a final problem: qualitative considerations about educational needs will always be exposed to the charge of "subjectivity". Many controversial issues and some speculation about the future are involved. It is not important to obtain a complete consensus of opinions. An aroused interest in the basic aspects of design education is much more essential. There is ample room for a difference of opinions but they have to be based on a clear recognition of existing facts. From this viewpoint, the present investigation can serve as a guide through a somewhat labyrinthic situation.

As a practical goal, it is hoped that this report will initiate and stimulate discussions, accelerate a process which seems inevitable, and serve as a catalyst in a field where urgent action is required.

2. GENERAL CONSIDERATIONS

2.1 Developments after World War II

Soon after the second world war, aeronautical engineering education took a clear turn toward increasingly sophisticated analysis, thorough-going research, and laborious testing. This trend was accelerated later due to Sputnik, missile systems, and the lunar program.

For more than two decades engineering education underwent a steady evolution of momentous importance. The struggle to advance the frontiers of knowledge resulted in ever-increasing emphasis on research and analysis. There was much need for intensifying the scientific aspects of engineering but in the process the borderline between science and engineering became blurred. This was unfortunate. Some confusion was evident, for instance, as several of the leading universities awarded the highly respected engineer's degree to clearly science-oriented graduates. Engineering was headed toward losing its identity and forgetting its purpose.

A change began to develop very gradually. Von Karman, who combined a scientific mind with an engineering outlook, made the distinction that the scientist explores what is, while the engineer creates what has never been. During his last years he termed it the main task of our engineering colleges to teach how to proceed from the theories of the scientist to the practical conclusions of the engineer (Ref. 1). Another distinct voice was raised by Ramo who recognized the emergence of a new pervasiveness of engineering (Ref. 2). This took place in the early 1960s, at a time when engineering education was fully preoccupied with emphasizing the theoretical content in engineering curricula and with solving well-specified problems by analytical methods.

By the late 1960s a general awareness began to develop that technological problems have to be solved within a rapidly changing overall climate. Our perspective is shifting from a consideration of technology for the sake of science to technology for the sake of society. The aircraft designer finds himself in the midst of such considerations. He has to take into account the side effects and long-range consequences of producing subsonic, supersonic, hypersonic, STOL, or VTOL aircraft. He has to be prepared to take responsibility not only for the technical quality of his design but also for its significance within our society.

One could also consider a different viewpoint. Human endeavor reaches over a wide spectrum. On one side there are the extraordinary accomplishments of our technology. On the other side there are miserable failures like wars and urban conditions where age-old problems of human relationships and emotions play the dominant role. Between these two extremes there are endless numbers of valiant efforts which are condemned to failure due to a lack of available means or of thorough preparation or of understanding the full complexity of the problem. Many engineering projects are in this category.

In spite of a solid educational foundation and much practical experience, engineers in the aircraft industry may easily find themselves caught in technical surprises of a most harassing and disquieting kind. We are reminded that the two largest aircraft projects during the decade from the early sixties to the early seventies resulted in years of unfavorable newspaper headlines and debate which were frequently linked with design problems. And we realize that with the introduction of promising new materials and new types of aircraft more design difficulties will have to be anticipated.

Only a fine line separates supreme accomplishment from dismal difficulties. The basic problem in aircraft design has always consisted of recognizing this delicate line. With ever-growing complexities this has become an extremely arduous task.

2.2 Importance of Design

For many years complexities in the practice of aircraft design have been increasing exponentially while design courses in aerospace curricula at most universities have shown a steady decline. The full seriousness of this situation was pointed out in a special statement by the AIAA Aircraft Design Committee (Ref. 3). A glaring discrepancy is seen between what is offered and what is needed in design education.

An awareness of serious problems in design developed at the same time as the first manned landing on the moon demonstrated what kind of achievements are possible when a unique effort is exerted. For aircraft development, however, we have to labor under routine conditions with stringent economic requirements and every-day real-life complexities -- very different from the scientific environment at the Houston Space Center or Cape Kennedy launching pad.

Scientific knowledge and analytical problem-solving techniques are necessary but by far not sufficient requirements for the designer. A consideration of design problems requires qualities like creative thinking, engineering judgment, and insight beyond pure technology. Among many other aspects, for instance, the impact of scale or size must be understood to anticipate constraints on expansion.

There is a wide gap between recognizing such design requirements and implementing them. Unfortunately, they cannot be taught readily. Even if methodology, concepts, and tools can be taught, a real-life laboratory is still necessary to give them meaning. A climate has to be provided where the qualities which have always been typical of a good engineer are appreciated and where they can develop. Fundamental problems in engineering education go deeper than developing quantitative capabilities.

Among the many aspects of design, there are two considerations of special significance: firstly, on the technical level, we must understand the full complexities and interactions inherent within modern technology; and secondly, beyond the technical level, we must understand the broader implications of technology on society at large.

The first aspect of technological complexities and interactions results in the need to coordinate the work of many specialists, to recognize and resolve ill-defined problems, to balance novel ideas with past experience, to recognize uncertainties, to evaluate risks, and to make decisions. Such capabilities go far beyond scientific expertise. We know from experience how long it takes to instill the student with the capacity just to think analytically. By comparison we can appreciate the magnitude of the task to develop an additional engineering attitude which is directed toward integrating real-life complexities and abstract knowledge. This is something new and must be recognized as a major challenge within the field of technology.

The second aspect regarding the broader implications of technology has caused wide-spread concern about social needs such as urban transportation, ecology, or limits to growth. Technology has been put under attack as the villain that has caused our problems with energy, pollution, and quality of life, and the engineer has to take the brunt of it. He realizes with dismay that traditional engineering education has not prepared him at all to cope with side effects and long-range consequences of technological developments. Again, new kinds of insight and methodology are needed and they reach far beyond the field of pure technology.

2.3 Special Role for Aircraft Design

It appears that the roots of many problems in aircraft design can be traced to a fundamental need to understand how to make decisions under complex conditions, including non-technical parameters. Lessons learned in this field will apply to many other technical and also non-technical problems and may be considered to represent somewhat of a classical education in a technological world.

Today, in a complex technological world, we have to face endless variations of a fundamental dilemma: we have to make decisions of great consequence in view of so many parameters, risks, and uncertainties that our traditional methods of approach are completely overtaxed and inadequate. A new insight has to be gained about perceiving and controlling a multitude of interactions. This cannot be done adequately on an abstract level. A real-life subject has to be considered which is complex but which can still be understood in its entirety.

Aircraft design may serve as a paradigm for developing this kind of understanding. The emphasis is on combining highly developed specializations with an imaginative spirit in the face of many uncertainties and also on paying full attention to details and necessary compromises without losing sight of the goals. With this general perspective, education in aircraft design can assume a role of significance beyond its own immediate field if this education is broadened -- as it must be -- to take into account the non-technical and non-physical environment.

A good example for the basic potential of aerospace engineering is provided by the Urban Technology Conferences of the early 1970s. Sponsored by engineering societies and public interest organizations, urban problems are attacked through the transfer of new technology -- with the aerospace community playing an important role.

Such basic musings about the role of engineering education in general may easily lead toward recognizing a particularly demanding role which education in aircraft design plays. The aircraft designer has to follow a very narrow path between "too heavy" and "too light" and the penalty for the slightest error may be extremely severe. The problem of fatigue is a typical example. Mechanical engineers recognized it, did some pioneering work, but nevertheless lived with it for a century until it loomed into the foreground and had to be attacked on a broad front due to the demands of aeronautics. More effort is required in aeronautics than in other fields of engineering.

2.4 General Aspects of Education

In earlier days, classical education in a non-technical world was directed toward developing an insight about life in ancient Greece and a corresponding value system. The underlying reason was that Greece represented a manifold but compact world which could be understood in its entirety. The educated person would apply such understanding to many other problems.

The humanist's emphasis on qualitative values fell short when technological developments required quantitative perception. On the other hand, scientific education with its emphasis on quantitative perception falls short because quantitative values are meaningless unless they are based on a qualitative value system. Both qualitative and quantitative understanding have to be combined to complement each other and to guide us in decisions we have to make.

This guidance was expressed qualitatively in the classical education of the Western World by the Latin quidquid agis, prudenter ages, et respice finem -- whatever you do, do it prudently, and consider the consequences. In the world of engineering it is expressed quantitatively as an analytical model with iterative loops and mathematical relationships. Both are aiming in the same direction, each with its own one-sided short-comings. The basic question is whether it will be possible to bridge the gap between these two approaches and to join and blend mathematical sophistication with an understanding of qualitative values.

3. SPECIAL CONSIDERATIONS

3.1 Fundamental Aspects of Design

Aircraft design is concerned with bringing together various fields of technical specialization and considering them as an entirety. Such fields of specialization include aerodynamic performance, stability and control, structures, materials, propulsion, electrical and hydraulic systems, avionics, reliability, maintainability, human factors, manufacturing, and logistic support, with well-defined responsibilities in each.

These specific fields indicate specialized applications of the aircraft designer's responsibility. The fundamental aspects of his responsibility are expressed by a set of common characteristics which are the same in any field of design:

- balancing contradictory demands from specialized fields against each other (technical trade-offs);
- taking into account cost effectiveness and time schedule (project trade-offs);
- assuring reliability, maintainability, and repairability (operational readiness trade-offs);
- satisfying given requirements and specifications;
- anticipating future modifications and developments;
- investigating poorly defined interactions between specialized fields;
- appraising uncertainties and making decisions in a subjective, stochastic framework;
- finding an optimal solution with due regard to all aspects.

An education in aircraft design has to prepare the engineer for a thorough understanding of these challenging and absorbing tasks. This requires an attitude which is not satisfied with solving single-answer deterministic problems but rather keeps inquiring and probing into the subjective and not-so-obvious and which aims at optimizing multi-answer probabilistic problems. Traditional methods of specialization have become quite inadequate for purposes of engineering education in view of ever-increasing interdependence, complexity, and change.

3.2 Subproblems

The magnitude of the overall problem may be recognized by listing some sub-problems:

a. Our educational system in engineering has for a long

time consisted of a two-step sequence: a science-oriented university curriculum is followed by a slow process of acquiring practical experience in industry. Interaction between theory and practice is at the root of most problems for the aircraft designer but the student is poorly prepared for this interaction. How can the educational process develop an attitude which combines theoretical understanding and practical outlook ?

b. The half-life of modern engineering education is rather brief. By the time a university-graduate has acquired some broader practical experience, his theoretical background may easily be obsolescent. On the other hand, a top man in the theoretical field will often lack an understanding of practical aspects. An answer will have to be found in the field of continuing education. How can continuing education be made an integral part of professional life ?

c. The demand for aircraft designers underwent considerable fluctuations in recent years and severe cutbacks took place in aerospace. Unfortunately, many engineers were not only unemployed but also unemployable because they were narrow specialists who could not readily adjust to other needs. Over-specialization has been found to contain many dangers. How can specialized knowledge be combined with a broader engineering education ?

d. Aircraft design generally takes place at the frontiers of technical developments. Research and testing are inseparably interwoven with application in each of the specialized fields. How can a spirit of rigorous scientific research be combined with the uncertainties inherent in any new development ?

e. New developments require new methods and new approaches. Many of them originate in industry where most of the practical experience is accumulated. The need for close coordination between industry and universities is obvious but considerable difficulties exist. How can universities be made more responsive to important developments in industry ?

f. Aircraft design includes the larger aspects of the overall system (e.g. performance, airworthiness and cost effectiveness) as well as minute attention to all details of design and production. It incorporates all the real-life complexities -- technological, economic, social, and environmental -- and consists of a continuous process of decision-making in view of many uncertainties. How can the mind be prepared to cope with such a wide range of demands ?

g. Aircraft design requires a particularly rigorous approach and may serve as a model for many other disciplines. How can the lessons learned in aircraft design be utilized for other applications ?

h. Design is considered by some to be an art, by others to be a science, and by others to be "what engineers do". There are gifted designers who do intuitively what must be learned slowly by

others. How can natural gifts in this field be recognized and stimulated ?

i. Design is creative work. It represents a unique combination of creativeness with analytical methodology. Much attention has been given to analytical methods in the present education of aeronautical engineers, but not much to stochastic methods and to the poorly defined question of creativity. How can the proper combination be developed between an analytical mind and a creative spirit ?

3.3 Method of Approach

The preceding considerations indicate the kind of observations and questions which can easily come to one's mind when education in aircraft design is discussed. The 1950s and 1960s were highly successful decades for the aerospace industry. Simultaneously, aerospace curricula were characterized by increasing emphasis on research and analysis.

Why is there a basic need for design and synthesis when a spirit of research and analysis appeared to be coupled with past successes ? Before an answer to this question can be found, a sequence of steps has to be taken. This is done in the appendices.

First of all, the situation as it presently exists in education for engineering in general, for aerospace engineering, and for aircraft design is clarified in Appendices A to F. Then the corresponding educational problems due to expanding concepts in design are identified in Appendix G. Finally, Appendices H to N provide a perspective for recent developments regarding relations between universities and industry, professionalism in engineering, continuing education, educational media and methods, engineering technology, and supply, demand, and economics.

To avoid distraction by details the reader may prefer to postpone perusal of the appendices. The summarizing remarks of Sections 4 and 5 lead directly to the principal findings of Section 6 and to the conclusions of Section 7.

4. SUMMARIZING SOME RECENT DEVELOPMENTS

The detailed considerations contained in the appendices will be summarized briefly in the following remarks.

4.1 Definitions and Interpretations

To avoid basic misunderstandings, clear definitions have to be given for the basic concepts used in the report. They include the terms education, science, engineering, engineering technology, and design (App. A).

Of all the potential misunderstandings, none is more common or more fraught with confusion than the ambiguity embodied in the word "design". The concept of design has recently undergone and is still undergoing a fundamental change which must be understood thoroughly and completely.

A renascence of design as a prime function of engineering is taking place. Development of basic concepts and integration of diverse aspects are recognized as central responsibilities. Dreary details of drawing board and nuts and bolts, which were considered to occupy such an essential place until the recent past, are in the process of being relegated to the background. Detail design is considered to be a technical sub-function, quite important of course, but much of it to be assigned to computers which are assuming an increasing share of the routine work.

With this new outlook, design comes into its own as the planning stage of engineering. Methods of both analysis and synthesis are essential for design and have to be combined into an integral whole. Analytical methods start from a clearly stated premise and lead up to a single answer obtained by deductive reasoning. Methods of synthesis, on the other hand, are directed toward a goal which has to be approached by inductive thinking and where an optimal solution has to be found among multiple answers as shown in Appendix G.

4.2 General Engineering Education

Before a discussion of education in aircraft design can begin, educational developments in general engineering and in aerospace engineering have to be considered. Three aspects of general engineering education are discussed in Appendix B.

A historical perspective in Section B.1 indicates that engineering curricula since the early 1950s have been characterized by their orientation toward science and research but that in the 1960s new interests toward design and toward a more meaningful liberal education began to emerge slowly. These new trends are well documented and have found an official recognition in the revised ECPD criteria for 1972-1973.

Section B.2 indicates that it takes a long time for new trends to

develop to maturity. Particularly the starting period is very slow. This is quite significant for the present situation in design and it appears that much can be gained by stimulating general awareness and discussion in this field.

Section B.3 gives three examples for a new spirit in engineering curricula. In all three universities much emphasis is given to design and to the integration of humanities and social sciences in the engineering program. One of the three programs was started only recently but the other two are well established and the results have been outspokenly encouraging. They show that the difficult problem of introducing new subject matter into an engineering curriculum can be solved and that a new emphasis can be given to design aspects but that a solution has to be based on clearly defined objectives and on a thorough reevaluation of conventional procedures.

4.3 Aerospace Engineering Education

The discussion in Appendix C traces the reasons for the research-oriented climate in aerospace faculties and curricula. A steady development toward increasing emphasis on research and analysis has taken place. Additional aspects of this situation, in line with the developments in general engineering education, are considered in Appendix H.

Some general observations are shown in Appendix C regarding typical aerospace curricula. There is no indication yet of any emphasis on design, synthesis, and systems as a particularly important aspect of engineering education.

As background material, Appendix D gives brief outlines of five selected aerospace curricula and Appendix E lists statistical data on some fifty aerospace-oriented departments which offer ECPD-accredited programs.

4.4 Aircraft Design -- as Taught Traditionally

Appendix F considers typical design courses as they have been taught within research-oriented curricula at a good number of universities for a long time. Traditionally their objective has been to offer an opportunity to expose the student to practical engineering problems and they have served as a capstone for many aeronautics curricula.

In sum, Appendix F indicates that this objective of a design course can be attained only when a considerable effort in terms of student time and faculty time is expended. Interdisciplinary aspects frequently make team teaching desirable. A principal consideration is that the course can be meaningful only when it is taught in close connection with recent industrial experience. This type of experience, however, is not easily available in research-oriented faculties.

4.5 Expanding Concepts in Design

Appendix G goes into considerable details about the role of the aircraft designer in industry and, correspondingly, a functional analysis of his responsibilities. This leads to a clarification of educational needs in aircraft design.

The design process is shown to consist of three phases: Firstly the conceptual phase where the designer roams creatively over the whole field and considers basic aspects, alternative possibilities, and future consequences; secondly the formative phase where a methodical process of decision-making is most important; and thirdly the final phase with meticulous attention to all details. Throughout these phases the responsibilities of designer and analyst are closely interwoven.

The main attention is directed toward the formative phase. This has to combine the methodical approach of decision-making with a design attitude which always keeps probing the limitations of available methods and theories. Decision-making includes probability and statistics, modeling, synthesis and analysis, evaluation, and optimization -- subjects which are fairly well established but should be integrated within an engineering curriculum. A general design attitude includes an awareness of real-life complexities which requires experience but for which the ground can be well prepared by using available case studies.

As an outcome of these new concepts it can be seen that it is not enough to expose the student to practical engineering problems as it has been done in traditional design courses. Important as such courses are, they have to be supported by a broader basis of design methodology which is required in view of ever-increasing complexities in design.

4.6 Universities and Industry

Appendix H considers the unfortunate situation which has developed as universities and industry slowly drifted apart. Design has been neglected at universities while industry needs university-educated designers. To teach design requires a combination of practical experience and theoretical understanding. Not much effort has been made to attract this type of talent to universities and Appendix H indicates some pertinent steps to bring universities closer to the realities of engineering practice.

Another aspect considered in Appendix H is the lack of available data on educational profiles for engineers in industry. No thorough investigation seems to exist regarding educational requirements for various types of engineering work.

4.7 Professionalism

Appendix I discusses an outlook which is not generally acknowledged by engineering faculties: The methodical decision-making process, which is such an essential part of design, can be considered to be a particularly distinguishing feature of professionalism in general.

One aspect of this outlook points toward the basic need for humanities and social sciences; they are concerned with the value systems which are used for decisions affecting more than purely technical considerations. Another aspect indicates that an undergraduate education majoring in aircraft design can serve as an excellent preparation for professional schools even in completely different fields, including non-technical professions. Such an education, based on the expanding concepts discussed in Appendix G, provides an outstanding opportunity to apply the decision-making process to complex conditions.

4.8 Continuing Education

Much pressure of time is caused by the dual need to preserve the established values of research-oriented education and also to recognize the rediscovered and expanded values of design-oriented education. Relief may be provided by incorporating continuing studies as an integral part of the educational process.

Appendix J gives a survey of recent developments in the field of continuing education. Two different aspects can be distinguished: firstly to update, upgrade, and broaden general knowledge; secondly to stretch professional competence by bringing to life the knowledge developed by researchers and the experience gained by practitioners in a specialized field.

Both aspects have to be coordinated with regular curricula and the whole field is still in an early stage of development in spite of a proliferation of efforts. Many possibilities exist for faculty involvement and closer relations between universities and industry.

4.9 Educational Media, Methods, and Content

In addition to continuing education, new media and methods in education have to be considered. The whole field has been growing rapidly and it is not easy to see it in the proper perspective.

Appendix K gives a survey of educational methods and media. Many possibilities exist for individual action but general changes are expected to take place only slowly. Preparation of text material is a field of special importance.

Appendix L gives a table with characteristics and costs of instructional media. Appendix M describes the main features of the Keller Plan as just one out of many examples of new teaching methods.

4.10 Supply, Demand, and Economics

The final Appendix N considers several general aspects. It begins with discussing the economic number of students in a departmental program and continues with giving statistical data on the stagnation in general engineering enrollments and the precipitous drop in aerospace enrollments during the last few years. At the same time enrollments in engineering technology programs have shown an

amazing growth. This leads to some basic questions regarding educational needs in engineering vs. engineering technology.

5. SUMMARIZING THE PRESENT SITUATION

5.1 Background

We may begin with some basic premises which provide the background for the present situation in aircraft design education.

a. The outstanding feature of aerospace education during the past two decades has been an increasing emphasis on the analytical methods of science. This aspect of our educational process can take full credit for some important accomplishments:

- Completion of the lunar program provides evidence that an engineering project of immense complexity and complete novelty can be carried out successfully as a clearly directed, unique effort. This was done under rigidly controlled conditions where development and operation took place on a pure level of science and engineering and where budgetary considerations were not pressing.

- The present system of jet transportation provides evidence that an engineering operation of great complexity can be carried out successfully as a routine effort. This is done under conditions where engineering has to foresee unpredictable everyday interactions and where budgetary considerations are reasonably constraining. Important in this case is the sequence of a systematic and very gradual development process. The Boeing 747 was preceded by the 737, 727, 707, B-52, etc; the DC-10 was preceded by the DC-9, DC-8, DC-7, etc; corresponding stepwise developments took place in the fields of navigation, communication, traffic control, etc.

b. On the other hand, aerospace education during the past two decades has suffered from a decreasing interest in the design aspects of engineering. This has caused considerable concern:

- Difficulties experienced with the development of new military aircraft during the last decade have had many contributing causes but recurrent themes among them have to do with system complexities and with the advancement of the state of the art. Both come close to the root of design problems. However, extenuating circumstances are often claimed due to a lack of realism in schedules, budgets, and procurement policies which can aggravate existing problems -- reflecting on managerial problems.

- A wide gap has developed between research-oriented universities and practice-oriented industry. This gap goes far beyond the traditional difference between theory and practice. Basic questions of professional outlook and subject matter are involved.

- Practical design experience in industry is represented by the "old breed" of designers educated mostly before the 1950s. These experienced designers are fading away slowly and not much is done to prepare their successors.

- The indifference of most universities toward design education is greatly influenced by basic policies. Selection and promotion of faculty members usually favor a background of research and scientific specialization much more than practical experience gained in professional life.

c. During the early 1970s a number of events took place which make the present situation particularly propitious for a basic re-evaluation of aerospace curricula:

- The aerospace industry had to lay off ten thousands of engineers and scientists, did practically no hiring for over three years and the yearly enrollment of incoming students in aerospace curricula dropped from over 3,000 to about 1,000 (see App. N.4).

- Cutbacks in space programs have resulted in a shift of emphasis in aerospace. Aircraft developments are resuming a larger share after a great part of the available resources was directed toward spacecraft during the 1960s.

- A long-term trend became visible indicating an increasing percentage of students enrolling in engineering technology and a decreasing percentage in engineering. The baccalaureate programs in engineering technology have not yet had an impact on the aerospace industry, partly because their recent rise coincided mostly with a no-hiring period in aerospace. Much clarification is necessary to identify the purpose of education in engineering and in engineering technology (see App. N.3).

5.2 Goal of Design Education

The role of design as the basic planning and decision-making stage of engineering is described in Appendix G. The corresponding goal of design education can be considered to be the development of the student's capabilities to conceive ideas and to provide for carrying them into effect.

Education in aircraft design requires first of all the development of a scientific mind to understand basic laws of nature and analytical techniques for applying them. Present curricula are well prepared to deal with this science-oriented aspect and no further discussion of it is warranted in this report.

A second requirement is directed toward the development of methodology and attitude to understand intricate relationships between theory and practice in both technical and non-technical fields. This design-oriented aspect has been orphaned in most

present curricula. The implications of this situation are the subject of the present report.

5.3 Main Issues

Several main issues emerge from the considerations shown in the appendices.

a. Basic design needs, which have to be met within aerospace departments, include

- recognizing the basic role of design,
- developing design-oriented education,
- and finding the proper balance between research-oriented and design-oriented education.

b. Considerable clarification is required in the border regions between engineering technology and engineering.

c. The tendency to overload engineering curricula has to be overcome. New means which are offered by continuing education and by educational methods and media have to be evaluated.

d. Fluctuations in aerospace employment make it necessary to take a new look at basic needs and objectives in aerospace engineering education.

e. Objectives in engineering education have to be based on a well-defined concept of professionalism in engineering.

6. PRINCIPAL FINDINGS

Education in aircraft design is a subject of a great many facets. Due to its rigorous demands, it forms a particularly significant aspect of the broader field of general design education. Many of the conclusions are applicable to other fields of design.

The following principal findings are based on the discussions as shown in the appendices.

6.1 Basic Needs

Under basic needs we can summarize several steps which have to be taken on the curricular level and which are ready for deliberate implementation. They are essential for design education.

a. First of all, any considerations of design have to make sure that there is no misunderstanding regarding the interpretation of design (see Section 4.1 and Appendix A).

b. The student's awareness of the design outlook must be developed throughout the curriculum. Present engineering curricula are directed toward methods of analysis. Additional concepts of synthesis can be introduced into conventional courses in various places in form of "mini-design" problems. This requires a moderate effort, with support provided by a systematic development of corresponding course material (see App. G.9).

c. An understanding of design methodology is of basic importance. This is beginning to be generally recognized, but in many cases the subjects are taught as electives and only seldom are they fully integrated within the curriculum. It is important to teach these courses from an engineering viewpoint as opposed to the somewhat different viewpoints of operations research and management. This requires a major effort (see App. G.4).

d. When the basic aspects of design methodology are understood, an attitude has to be developed which recognizes practical limitations of the methodology. This should be based on experience. However, the time period required to gain such experience in practice can be condensed considerably by introducing case studies of real-life problems in the curriculum. Much mutual benefit for students, industry, and universities could be derived from a new outlook in this field of education. A considerable amount of systematic work has been done about case studies, and reports on accident investigation provide much text material in the field of aircraft design. Only a relatively small effort is required (see App. G.9).

e. Beyond understanding real-life problems on a technical level, the student must develop an understanding of the broader implications of technology on society at large. Such understanding results in a value system which is the basis of the decision-making

process for major projects. Non-technical values are developed in the fields of humanities and social sciences. The allotted time for these subjects is generally sufficient but they are seldom taught in a way which is meaningful to the engineering student and which involves him in practical applications. A considerable amount of pioneering work has been done but a major effort toward close cooperation among faculties in engineering, humanities, and social sciences is still required (Ref. 4).

f. The creative aspects of design have to be emphasized. They cannot be taught but the student can be given an opportunity to develop them individually. Some work has been done in the field of freshman design courses. Such courses can also play a major role in motivating students and introducing them to the spirit of engineering. Considerable attention has to be given to this aspect. (see App. G.7).

g. The designer must be able to communicate -- orally, in writing, and in form of sketches. Technical report-writing as an expression of clear and logical thinking is only one aspect of it. A systematic effort in this field may produce better results than have been obtained in the past (see App. G.8).

h. A senior design course ought to incorporate as prerequisites many of the considerations described in items a through g. This represents a large step beyond the traditional aspects of team work and interdisciplinary coordination and it requires a major effort (see App. F.2 and G.10).

i. The basic outlook in design education should be that design can be considered to be the essence of engineering. Design education has to develop an awareness of overall engineering aspects. This awareness is needed not only for the designer and the project engineer but also, to somewhat varying degrees, for each member of the engineering team.

j. The preceding items form a long list of educational needs in aircraft design. The next step consists of combining these new design-oriented aspects with the research-oriented aspects of present curricula. This problem is recognized in the revised ECPD criteria (see App. B.1.7). They are based on enough flexibility to permit the expression of an institution's individual qualities and ideals and they also consider qualitative as well as quantitative factors to prevent "standardization and ossification" of engineering education. The proper balance between research and design has to be sought by each institution on an individual basis after its educational objectives have been established clearly.

6.2 Basic Challenges

Under basic challenges we can list several concepts which are of fundamental importance and are just beginning to emerge. They are visible but not yet generally recognized. A general awareness of these concepts and agreement regarding their significance will have

to develop before they can be implemented on a large scale.

6.2.1 Engineering and Engineering Technology

a. Going a step beyond the considerations of item 6.1.j, engineering education can be envisioned to contain three different aspects: engineering research for basic understanding, engineering design for developing new projects, and engineering technology for applying technical skills in support of engineering activities. Engineering research is firmly established in university curricula. Engineering technology is growing rapidly in separate programs. Engineering design, however, has been badly neglected and must first be developed in accordance with Section 6.1.

b. Each of these three aspects is of vital importance and none can exist in the long run without the others. Agreement has to be reached on the best ways and means for balancing research-oriented, design-oriented, and technology-oriented education.

c. This perspective is an expansion of item 6.1.j:

firstly, the proper balance between research-oriented and design-oriented education has to be found within universities, as indicated in item 6.1.j;

secondly, general agreement has to be reached on the educational objectives in engineering design and engineering technology -- a subject still much discussed in universities, technical institutes, and professional societies (see App. N.3).

d. No quantitative data exist about the percentages of engineers served best by an education oriented toward research, design, or technology. Much clarification is required in this field. There is considerable conjecture about the numbers of engineers doing work for which a technologist would be as well or better prepared (see App. H).

e. Among the three aspects of research, design, and technology, design occupies a central position. At one end it overlaps with research, at the other end with technology. Since many students find out quite slowly, often only after they have obtained their B.S. degree, for which of the three aspects they are suited best, it stands to reason to make design an essential part of undergraduate curricula because of its central position.

f. As engineering education is shifting toward an increasing emphasis on interaction between technology and society, education in engineering technology will have to take over many technical fields which have been the prerogative of engineering. Such fields of engineering technology include detail design, materials engineering and selection, production engineering, quality control, non-destructive testing, instrumentation, maintenance engineering, etc. This leads to some very fundamental questions regarding which

subjects should be taught where and when and by whom ? Answers will have to develop gradually.

g. Delimiting the educational objectives in engineering and engineering technology along these lines, it becomes obvious that career mobility between these two educational fields must be provided. An engineer's career may easily lead him to a position where he needs the technical skills of an engineering technologist and vice versa. An answer will have to be found in continuing education.

6.2.2 Educational Effectiveness

Any modification of existing curricula has to overcome restrictions imposed by time limitations. The 1968 report on Goals of Engineering Education looked forward to a 5-year basic professional degree within a decade as the most feasible solution. However, no consensus of opinions has developed yet and the following basic considerations lead toward an alternate possible solution.

a. Continuing education is discussed in App. J. It can be seen that the concept of lifelong learning finds growing acceptance; that scope and diversity of programs are fairly impressive; and that opportunities to pursue professional development free from the constraints of degree programs are offering a new outlook. Yet the whole field is still in an early stage of development and concerted action is needed badly. Engineering faculties have not taken much part in continuing education and hardly any coordination exists between regular curricula and continuing studies.

b. Such coordination could assign to an undergraduate curriculum the fundamentals of scientific understanding, of a systematic approach to the multifarious aspects of our technological world, and of a system of values. Continuing education would be directed toward the specialized and practice-oriented studies in accordance with the individual career pattern which each engineer has to develop for his specific needs.

c. Teaching the fundamentals, of course, has always been the goal of basic engineering education. Usually it had to be compromised because too many subjects had to be incorporated in the curriculum. This should not be the case if continuing education were well developed and coordinated along the lines indicated in item b. Then the undergraduate student's objective should be to develop a clear understanding of fundamentals, to learn how to learn, and to become motivated toward continuing studies. The definition of fundamentals may easily change in due course of time.

d. Educational methods and media provide many means to modify traditional teaching methods as discussed in App. K. There is no single solution. Each faculty member, each department, and each institution has to arrive at an answer in accordance with individual circumstances. Educational objective, curriculum, continuing education, educational methods and media, available text material, and

subject matter have to be considered as various aspects of the same educational problem.

e. Items b and c can lead to a modification of our present outlook in engineering education. In accordance with present concepts, the undergraduate curriculum remains the basis which offers two options to the graduate: either he continues with programs for advanced degrees or he enters engineering practice directly. There are, however, three new aspects:

> firstly, the undergraduate program is well-rounded rather than a preparation for future research work;
>
> secondly, entering engineering practice with a bachelor's degree implies that development of the full professional potential requires continuing studies;
>
> thirdly, continuing studies provide a multitude of options; they lead to an advanced degree if they either meet the objectives of a recognized program or complete a meaningful individual course of studies; otherwise they lead to professional certificates in chosen fields.

6.2.3 A Broader Basis

The slump in aerospace employment, the drop in student enrollments, and the lack of any reliable estimate about the future demands for aerospace engineers (see App. N) have created an outlook which is quite bleak unless some positive factors can be clearly asserted. Since the present demands of research agencies and industry hardly justify the existence of some fifty ECPD-accredited departments with aerospace-oriented programs (see App. E), the question arises whether an aerospace education can offer a sufficiently broad basis to prepare students for fields other than aerospace engineering. Some new aspects are shown in the following considerations.

a. Applications of fluid dynamics to bio-medicine and air and water pollution, or of light-weight structures to other transportation systems and construction problems, or of propulsion and energy conversion to many uses are some immediate examples.

b. A full answer requires consideration of an additional aspect. Fundamental changes in general engineering education as indicated by the new ECPD criteria tend toward increasing emphasis on design-oriented courses in line with items 6.1.b to j. New approaches and new courses have to be developed and the aerospace industry fortunately has had a headstart in developing the systems approach.

c. Education in aircraft design could well play a leading role because it occupies a unique position and aeronautics is a most versatile field. Its problems along the frontiers of our technical knowledge are applicable to an enormous variety of design problems which have to be solved throughout our technological

world.

d. Such a design-oriented approach can offer much to students from other fields. Emphasis will be on the very essence of engineering. Science, experimentation, and design can be integrated with humanities and social studies to form the basis of a liberal-technical education. This can occupy a position parallel to a liberal arts education. Completely new perspectives can be developed (App. I).

e. A good point can be made for a broadly conceived undergraduate curriculum in aerospace which develops both an analytical mind and a design attitude based on a liberal-technical foundation. The student can postpone the decision about his future career until he has received his bachelor's degree. His aerospace orientation is applicable to many fields of engineering and management. He is prepared to continue with graduate curricula in science and engineering or to enter industry or even to enter a school of medicine or a school of law without having lost any time if he chooses the proper electives.

f. This outlook is based on a recognition of the role of engineering and of aircraft design as a particularly significant aspect of engineering. It implies a concept of design which is directed not toward specialization but toward an understanding of the complexities inherent in a technological world.

6.2.4 Professionalism

a. As indicated in item 5.3.e, professionalism in engineering is not yet well defined. One interpretation, which is discussed in Appendix I, considers public-oriented and client-oriented aspects of the professions. Public-oriented aspects are characterized by a recognized responsibility for the decisions which affect the quality of some significant portion of the public environments -- including natural environments as well as health, social, legal, educational, technical, etc. environments.

b. It is apparent that such an interpretation has much to recommend itself to a designer's viewpoint. Decision-making, which is the core of the design process, assumes a central position and the designer's education is applicable to many fields as seen in Section 6.2.3.

c. Besides, a clear distinction between engineering and engineering technology follows from this interpretation. The engineer, in addition to his technical responsibilities, has to be prepared to make decisions which affect the public environment. A recent example is the case of the supersonic transport where considerations of pollution, noise level, sonic boom, passenger attitude, economics, national priorities, national prestige, etc. had to be included. Similar considerations on a smaller scale are typical of many engineering projects.

d. A significant shift of engineering responsibilities to include interactions between science, technology, and society was mentioned in item 6.2.1.f. This involves a great many aspects. Again, a unifying outlook for the diversity of aspects has to be found in the interpretation of professionalism in engineering.

e. The subject of professionalism in engineering, which seems to be quite remote from educational needs in aircraft design, actually requires some basic attention. Depending on its definition, the engineer will either assume the role of a specialist who solves given problems or he will assume a leading role in shaping future events so that technological problems can be anticipated and minimized. Design is the key instrument for shaping future events.

6.3 Basic Obstacles

The main obstacles to a design-oriented engineering education can be found in three fields: time, inertia, and money.

a. There is a superficial plausibility in the argument that present undergraduate curricula are overloaded as they are and that there is no room for additional design-oriented courses. Obviously some re-thinking will be required.

b. A remedy must not necessarily be sought in lengthening the time to obtain the basic professional degree. Instead, it may be found in a combination of three new aspects: Firstly, the knowledge explosion is accompanied by a knowledge implosion which makes it possible to condense and concentrate the learning of many subjects. Secondly, continuing studies can be made an integral part of the professional learning process. Thirdly, new methods and media can be used to make the learning process more efficient and effective.

c. These new aspects are sufficiently well established and enough experience has been gained with them to make them useful and practical tools in the educational process. Their introduction will have to overcome much inertia from faculty members. This is humanly understandable and will result in a process which has to be carried out judiciously.

d. Unfortunately, some research-oriented faculty members are inclined to see a threat in an emphasis on design aspects. This is unfounded. Both research and design are needed. The proper balance has to be found and some universities may be oriented more toward research, some more toward design. Other faculty members are reluctant to introduce new educational methods and media. Again, most changes can be expected to take place very gradually.

e. Inertia will have to be overcome not only among faculty members who have to face new approaches to teaching but also among practicing engineers who have to get used to continuing education as part of professional life. For many engineers, however, this is already a well-acknowledged fact and, of course,

it is fully established in the medical profession.

f. Financial obstacles are not prohibitive. Nevertheless, a considerable burden will have to be accepted by universities to encourage the development of new courses and to prepare educational aids. Such investments should to some extent be amortized in due course of time. Industry will be burdened with increasing costs of continuing education but here, too, clear benefits will be derived and it is a gradual process.

6.4 Consideration of Sub-problems

Among the special considerations of Section 3, a number of questions were raised regarding sub-problems in the education for aircraft design. The questions can now be seen in their proper perspective and it can be indicated where the answers will have to be found eventually. The following sequence corresponds to the sequence of sub-problems and questions in Section 3.2.

a. The educational process can develop an attitude which combines theoretical understanding and practical outlook by firstly introducing the practical aspects of design into the undergraduate curriculum and secondly making continuing studies an integral part of the educational process. The interaction between theory and practice is the principal subject of concern for continuing studies and course material has to be prepared in close cooperation between faculty members and practicing engineers.

b. Continuing education can also be made an integral part of professional life by recognizing the high standards to be expected in a top professional. The four years for a bachelor's degree and five years for a master's degree for engineers have to be compared to the six years for a master's degree in architecture, social work, or business administration and to the eight years for a professional degree in medicine. This indicates that the young engineer who expects to rise above the routine level must develop a career pattern for himself which makes full use of continuing studies. He has a time advantage over his brethren in many other professions by being able to practice while he continues his studies.

c. A broad engineering education has to be the foundation on which specialized knowledge can grow. Design methodology is an important part of this foundation. Then, if one branch of specialization does lose its usefulness, another branch can be grafted on the same foundation. Otherwise one would have to start from scratch. Again, the field of continuing studies should facilitate any adjustments.

d. A spirit of rigorous scientific research can be combined with the uncertainties inherent in any new development by developing a design attitude. Such an attitude recognizes the spirit of scientific research as well as the uncertainties of real-life complexities. Case studies develop a feel for the interwovenness

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of research, design, testing, and application.

e. Universities can be made more responsive to important developments in industry when faculties become interested not only in the research problems but also in the design problems occurring in industry. This will necessitate much closer contact. As a result, communication between universities and industry can be a two-way road, with theoretical knowledge coming from universities and practical experience coming from industry.

f. In order to cope with the wide range of overall and detail demands in aircraft design, the engineer's mind has to be stretched. This can never be accomplished fully in university courses, no matter over how many years. It requires the foundation of a good engineering curriculum combined with engineering practice and continuing studies.

g. The lessons learned in aircraft design can be utilized for other applications since they consist of combining real-life complexities with a methodical decision-making process. This kind of combination is at the root of many problems.

h. We know only little about recognizing and stimulating natural gifts in the field of design. One aspect is that we should not crush intuitiveness completely by analytical methods and that the student should have an early opportunity to see how engineering consists of more than analysis.

i. Finally, to develop the proper combination between an analytical mind and a creative spirit -- this is a task for which we dare not yet to give an answer.

6.5 Viewpoint of University Administrations

University administrations have to provide direction and encouragement for new developments. With respect to the development of design aspects in engineering curricula in general and aerospace in particular, this means:

a. The role of design subjects has to be defined within the established goals of the institution; interested faculty members have to be identified; basic principles have to be discussed; and responsibilities for initial action have to be delegated.

b. Administrative policies have to be developed to encourage faculties about spending time on preparation of design courses and text material, on interdisciplinary contacts, on relations with industry, and on advising students in connection with individual design projects. This type of work is discouraged by the far-spread publish-or-perish syndrome. Wherever this syndrome has taken root, it can usually not be overcome by a simple statement but its modification has to be stated clearly, explicitly, unequivocally, and repeatedly so that no misunderstanding is possible.

c. Administrative policies have to be considered to establish close contact with industry. Temporary appointments of visiting or adjunct professors from industry may be contemplated.

d. Administrative policies have to be established with regard to the support of educational aids and delimitation of fields of interest in continuing education and engineering technology.

6.6 Viewpoint of Individual Faculty Members

Individual faculty members in engineering and aerospace should familiarize themselves with the developments which have led to the new ECPD guidelines and their increased emphasis on design aspects. This may help to establish their particular field of professional interest somewhere in the spectrum from research to design. Some basic considerations include the following:

a. New developments in education take place gradually. This gives time for individual adjustment and possibly for the development of a personal interest in some aspects of continuing education or preparation of course material.

b. Design has many facets. Decision-making and optimization require coordination with operations analysis; needs analysis, impact analysis and value systems require coordination with humanities and social sciences; and the main part of a design project requires close contact with industrial practice. In all these fields much work has to be done to develop a meaningful design course and to instill the spirit of design in the student.

c. Continuing education provides a particularly rewarding field for cooperation with interested industry located in the vicinity of a university. For courses at the forefront of knowledge a seminar format may be most appropriate as the practicing engineer's experience and the faculty member's theoretical knowledge can make it difficult to distinguish between teacher and learner.

d. Educational methods and media can provide endless variations. Care should be taken not to get lost in too much experimentation. Basic aspects are well established and written up. Faculty members who have particularly good course material, preferably in small packages, should definitely check the possibility of making it available to a wider audience.

e. There is also a wide open field in the development of course outlines and corresponding text material on problems of interaction between materials and structures -- like fatigue, stress corrosion, fracture mechanics, and fibrous materials -- or on risk evaluation and decision-making in engineering. This has to be done in closest cooperation with the practical experience accumulated in industry and it will also require cooperation of various specialists.

f. Finally it should be kept firmly in mind that any newfangled possibilities must stand the test whether and under what

conditions they are better than the old-established methods. And, last not least, a good teacher must master the art of giving a lecture, taking part in a discussion, and having a dialogue. Video-taped sessions for self-improvement should be available and frequented at all universities.

6.7 Viewpoint of Policy-Making

a. An increasing emphasis on design aspects will require guidance and leadership to coordinate research, development, application, and teaching. There is no example in the field of engineering education where a large-scale effort of such complexity and so much interaction was initiated. It had been much simpler during past decades when scientific content in academic curricula was intensified because fields of specialization could be neatly separated. Design, however, requires close interdisciplinary relations and full coordination between universities and industry.

b. Education in aircraft design is at the threshold of new developments. The situation is complex and dynamic as new ideas will take shape and will have to be evaluated. During this period of development precious time and limited resources are likely to be misspent unless some guidance and direction are provided.

c. Such guidance should serve the purpose to provide visible direction, to encourage promising efforts and, if needed, to sound an early warning voice with regard to developing trends. Attention might also be directed toward new fields where the development of course material is urgent.

d. For complex organizational problems in industry much benefit has often been derived from the advice provided by independent groups of capable advisors. Frequently they are established as trouble shooters after difficulties have developed. If established in time, they can recognize difficulties before they assume major proportions. Good examples can also be found in advisory boards at universities.

e. An advisory board on education in aircraft design could possibly provide the guidance which will be needed in a period of fundamental changes. Such a nation-wide board should be somewhat similar to university advisory boards as they exist at individual institutions. It might consist of about half a dozen people of recognized stature in the aircraft industry, in professional or governmental organizations, and in education who would convene once or twice a year to ponder educational needs in aircraft design and make recommendations. Such an advisory function should impose no obligation but should carry the weight of well-considered opinions expressed by highly qualified people.

6.8 Overall Viewpoint

As a final step we can bring together different viewpoints to provide an overall perspective for design education.

a. Design education must prepare the engineer to master the complexities of our technological world. This refers both to the pure technology and to the interaction between technical product and human needs.

b. Contrary to the fragmentation of viewpoints which is typical of specialization, design requires the development of an integral viewpoint. This will serve to bridge the gaps which exist between theory and practical application, between technology and society, between specialist and manager, and between diverse specialists.

c. As shown in Appendix G, design can be seen as the planning stage of engineering. It takes into account and integrates many fields of specialization and it requires a methodical approach and an attitude which are different from research.

d. Each university can establish an individual blend between research and design in accordance with its educational objective, admission standards, available talent, research facilities, and financial resources.

e. Design education is a lifelong learning process. The undergraduate curriculum cannot do more than assure a solid foundation in fundamentals. Among these fundamentals, basic sciences and engineering sciences are well established in present engineering curricula. However, much has to be done to teach engineering students the methods of decision-making as part of design and the fundamental aspects of humanities and social sciences as the basis of a value system.

f. Basic needs and challenges resulting from the present situation are summarized in Sections 6.1 and 6.2. They call for action and the time is ripe for it -- except that active interest, discussions, and involvement among faculty members leave much to be desired, in general.

g. The crucial spot where action has to take place is on the faculty level. It has been said, probably not without cause, that anything requiring faculty action will never get any results. This is a grave imputation. Would it not be pitiable and lamentable if that should really be true in this case ?

h. The educational situation in aircraft design is quite unique. External circumstances after the aerospace setbacks of the early 1970s encourage searching discussions, and much opportunity exists for individual initiative. It is not difficult to indicate what could or should be done. Whether it will be done, however, depends on the capability and willingness of each faculty member to recognize the basic changes taking place, to contribute in accordance with specific talents, and to respond to a genuine opportunity.

i. There is an additional aspect which deserves some consideration. Within the rational process of education we should reflect upon the affective aspects that teaching can be spontaneous and that learning can be joy. Design can be fun as well as a challenge. This depends on the satisfaction we can derive from our work. But satisfaction results from reaching for mastery -- whether this is concerned with the purely technological aspects of design or with its broader aspects of blending technology with human needs.

j. As a last thought we may recognize that the integration of many technical and non-technical considerations, which is such an essential aspect of design, is a part of a greater pattern. The final goal of any education should be an integrated human being. This is not a static state but a continuous process. "The mind is not a vessel to be filled but a fire to be kindled." It may have been Plutarch almost 2,000 years ago who expressed this fundamental truth or it may be of more recent vintage. Perhaps it provides the proper perspective for design education.

7. CONCLUSIONS

a. The fundamental problem was introduced in Section 1 in form of a question: How can the student combine an understanding of scientific theories with an awareness of real-life complexities ? The answer given in this report is: design education.

b. Design education must be directed toward developing a mind which can understand engineering details and can integrate them within an overall system.

c. Basic needs arise in the undergraduate curriculum. Beyond the subject material covered in typical present curricula, the student will have to develop an understanding for the design process as shown in Section 6.1. This calls for a fundamental educational effort over many years and is in accordance with the objectives of the Engineers' Council for Professional Development.

d. It also has to be recognized that we stand at the threshold of a new phase in engineering education. New demands and opportunities are emerging. Basic challenges consist of

- clarifying the distinction between engineering and engineering technology (Section 6.2.1);

- making continuing studies an integral part of engineering education (Section 6.2.2);

- establishing an undergraduate curriculum as the foundation for a liberal-technical education (Section 6.2.3);

- defining professionalism in engineering (Section 6.2.4).

e. An overall viewpoint as shown in Section 6.8 can provide the proper perspective for the entirety of the problem.

f. Recognition of these needs, challenges, and perspectives results in a new situation. There will be an outspoken demand for design-oriented faculty members who combine a scientific background with practical experience and design methodology -- presently a rare breed indeed. Some of them will have to evolve from previously research-oriented faculty. Others will have to be attracted from industry, with corresponding changes in academic policies regarding recruitment and rewards.

g. These problems are of special significance and urgency in the field of aircraft design. Design problems of the near future are concerned, among others, with the development of SST, VTOL, and STOL aircraft where a close interrelationship exists between technical feasibility and needs of society. In addition, the designer has to face technical problems of great complexity, including the introduction of newly developed materials. Highest standards for design education are important and imperative.

h. Education in aircraft design, although qualitatively not different from design education in general, provides a special challenge and requires a special effort due to the particularly exacting demands in this field. Whether these high demands can be met soon and effectively will depend on two factors:

- the initiative taken by members of aerospace faculties (Section 6.6);

- the guidance and direction provided on a policy-making level (Sections 6.5 and 6.7).

APPENDICES

APPENDIX A

DEFINITIONS AND INTERPRETATIONS

A.1 Basic Concepts

Clear definitions are essential for a valid discussion. Different people can easily have different interpretations for widely used terms and the following remarks should help to clarify some basic concepts as used in this report.

Education (derived from the Latin e-ducere, to lead out) can be understood as leading out of a state of ignorance. It has been described as a continuous process of inner growth, a state of readiness to learn throughout life, combining an inquisitive spirit with a discriminating mind.

Such an interpretation implies a dynamic process as well as a humble recognition of the magnitude of the task to overcome our ignorance. It is contrary to the more popular view of education as a commodity which can be purchased by attending college for a number of years. How many people think of themselves as educated persons without realizing that their mind has been closed to any new idea since they left college! Education is distinguished from training by an openness to look at broader problems, to have an unbiased mind toward new ideas, and to go beyond narrow specialization and limited applicability. It is not enough to train people to do things effectively by imparting the necessary skills. Beyond this, the mind has to be educated to recognize what is worthwhile and what is not and also what is fundamental and what is not.

The whole field of education is in a very lively state of flux. New educational concepts, aids and techniques are blossoming all over, traditional assumptions are questioned, and it appears that the young generation's desire for involvement and relevance goes along similar lines as the well-reasoned considerations of experienced educators. Much clarification is still required.

Science is concerned with understanding, describing, measuring, and categorizing phenomena as objectively as possible, i.e. independent of human values. The scientist is, of course, a human being and has his individual value system. It appears that acting as a scientist he must be ready to free himself from it so that he can obtain objective and reproducible results. In extreme cases he may have to make a choice between his loyalty to science or to his conscience. The atomic bomb, nuclear fusion, and lasers are examples. There is, however, considerable controversy on this subject.

Since science seeks fundamental understanding, a problem has to be simplified to its skeleton and abstractions have to be used so that

basic relationships can be clearly established and analyzed. Scientific exploration is the basis of our technology. It consists of analysis and de-composition. Its success and failure must be understood. Lunar landings were based on scientific methods under scientifically predictable conditions. The less propitious state of affairs regarding more worldly problems, on the other hand, indicates the limitations of scientific methods when real-life complexities have to be considered.

Engineering is concerned with creating technical products, devices and systems to satisfy human needs -- where "technical" pertains to the utilization of materials and forces of nature. Engineering is different from a mere application of science. It is a creative process, directed toward a specific practical purpose, giving full consideration to real-life complexities but at the same time making use of scientific principles. The most basic function of engineering is design which combines analysis and de-composition with synthesis and composition. All other engineering responsibilities depend on it.

Design has been defined in many ways (see also Section A-2). For the purposes of this report, design will be considered as the planning stage of engineering. As stated by Woodson in Ref. 5, it is an iterative decision-making activity to produce the plans by which resources are converted, preferably optimally, into systems or devices to meet human needs.

Important is what may be called the design approach -- a mental attitude which looks at all aspects connected with a problem. The essence of design is to develop a concept and provide for its transformation into a desired result. Much more is involved than a narrow formulation of instructions for manufacturing.

There is nothing new about this broad concept of design. It was practiced by the Romans when they built bridges and aqueducts, by the Egyptians when they built pyramids, by the Chinese when they built the great wall -- and by Douglas for the DC-3. A new aspect, however, is the complexity of technological systems as they developed with World War II and the methodology which is required for their design. This must be recognized with its full implications. Design is not just a byproduct of a good scientific education. It requires an educational process in itself. The basic role of design as the focus of engineering education had been an axiom decades ago, was then disremembered in the wake of emphasis on scientific contents, and is now slowly finding more general recognition again.

Aircraft design provides the central point for the present considerations. This should not be understood in a narrow sense. Aircraft, spacecraft, missiles, rockets, helicopters, ground-effect machines, and even some ground vehicles are parts of an entity which is held together by a common attitude. The pioneering spirit of working at the frontiers of technology, the challenge posed by the environment and natural laws, the

interaction between materials and structures, the ever-increasing complexity of new aspects and, above all, weight and cost effectiveness -- these are some of the common ingredients. Aircraft design is taken as particularly representative for this broad field because its cost constraints are more important than for spacecraft and its cost-weight effectiveness can be well established for commercial transports.

<u>Engineers, engineering technologists, and technicians</u> are concerned with distinctly different tasks in the technological field but have to work closely together. Engineers must be equipped with a thorough scientific background to think in abstract terms and to perceive technical tasks and functions before the hardware exists. Technicians, at the other end of the spectrum, must have the practical skill and understanding to perform technical tasks as the hardware becomes available. Between science-oriented engineers and hardware-oriented technicians there is a wide field where engineering technologists must perform a great variety of engineering tasks which are related more to application and practical aspects than to mathematical rigor. The difference between engineering and engineering technology is defined by the Engineers' Council for Professional Development as follows:

Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.

Engineering technology is that part of the technological field which requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer.

<u>Specialist, generalist, designer, system engineer, and engineer</u> are another set of designations which have been widely used and poorly defined. They all describe activities of people closely connected with design. The important function of the specialist is obviously to be knowledgeable and experienced in a specialized subject. An often-cited adage describes him as learning more and more about less and less until he finally knows everything about nothing while the generalist learns less and less about more and more until he finally knows nothing about everything. Between the two evils of narrow-minded specialization and vaguely expressed generalization, a seductive trend toward superficiality is particularly dangerous and has no place in design. It may be preferable to avoid the word "generalist" because, notwithstanding its basic validity, it is frequently used with a negative connotation of lacking depth.

The word "engineer" covers many fragmentary aspects, e.g.

aerodynamics engineer, structures engineer, materials engineer, test engineer, production engineer, sales engineer, maintenance engineer, etc. This distracts from the fundamental role of the engineer. It may be mentioned, with tongue in cheek, that in the English language the engineer is linked with the engine and this includes the man at the throttle of a locomotive. In French and German, on the other hand, the word ingénieur has its origin clearly in the Latin word for ingenious and radiates more prestige. Yet in Europe as well as in America there is much concern about the lack of professional recognition for the engineer. This problem is closely connected with educational aspects, professional activities and professionalism in general.

The roles of the designer and of the system engineer are particularly significant in this connection and will be discussed in Appendix G.1 and 3.

A.2 Various Interpretations of Design

The word design is subject to different interpretations. In an attempt to clarify the situation, it should be appropriate to begin with quoting from Webster's Third New International Dictionary (1961):

- Design (from Latin designare, to mark out)

- a mental project or scheme in which means to an end are laid down, i.e. a plan;

- a preliminary sketch or outline (as a drawing on paper or a modeling in clay) showing the main features of something to be executed, i.e. a delineation;

- the process of selecting the means and contriving the elements, steps, and procedures for producing what will adequately satisfy some need, i.e. specifically: the drawing up of specifications as to structure, forms, positions, materials, ... in the form of a layout for setting up, building, or fabrication.

Each of these three definitions refers to an essential aspect of the concept of design as it is used throughout this report.

There are a number of other definitions in Webster, including "a painter or sculptor's preliminary drawing or model"; "a conceptual outline ... of a literary or dramatic composition"; "a deliberate undercover project or scheme entertained with discreditable or hostile and often dishonest, treacherous, sinister, or seductive intent". These may be dismissed for our purpose but they indicate that the word design finds its application in a wide field ranging from art to roguery.

Some specific definitions may be quoted from recent books:

- Engineering design is an iterative decision-making activity to produce the plans by which resources are converted, preferably optimally, into systems or devices to meet human needs (Woodson in Ref. 5).

- An engineering design problem is typically stated as follows: Devise, subject to certain problem-solving constraints, a component, system, or process to accomplish a specified task optimally, subject to certain solution constraints (Dixon in Ref. 6).

- Engineering design is the activity wherein various techniques and scientific principles are employed to make decisions regarding the selection of materials and the placement of these materials to form a system or device which satisfies a set of specified and implied requirements (Middendorf in Ref. 7).

- Engineering design is a purposeful activity directed toward the goal of fulfilling human needs, particularly those which can be met by the technological factors of our culture (Asimow in Ref. 8).

Jones quotes in Reference 9 a number of additional definitions for design from which the following may be cited:

- A goal-directed problem-solving activity (Archer, 1965);

- A creative activity -- it involves bringing into being something new and useful that has not existed previously (Reswick, 1965);

- The initiation of change in man-made things (Jones, 1970).

In Reference 9 Jones considers design as a hybrid activity which depends, for its successful execution, upon a proper blending of art, science, and mathematics. The designer needs firstly the artist's attitude toward a multitude of alternatives, whether his medium consists of a sketch block or of the screen of an interactive on-line computer; he needs secondly the scientist's skeptical approach toward searching for truth and observing the results of a controlled experiment; and he finally needs the mathematician's methods of stating his assumptions in a few abstract symbols and manipulating the symbols to find an optimum solution after the problem has been defined.

As Jones points out in Reference 9, any attempt to isolate the essence of design is directed not toward the outcome of designing but toward its ingredients. Many kinds of design process are indicated in the variety of the preceding definitions and further material is contained in Reference 10 to 13a. It is particularly noteworthy that drawing -- the most common symbol of design -- plays a very subordinate role in recent discussions.

APPENDIX B

GENERAL ENGINEERING EDUCATION

B.1 Some Well-documented Recent Developments

The two decades from 1950 to 1970 reached from a period of anti-intellectualism over a period when science and technology were glamorized to a period when anti-technology became a fad. Eggheads, astronauts, and hippies served as symbols for changes in social attitudes and general climate at universities. Nevertheless, rapid expansion of educational and research facilities and generous funding were characteristic of the time.

The period of expanding research came to a halt around 1970 and we seem to have reached the threshold of a completely new era. New concepts different from any previous educational experience became recognizable in the middle 1960s, gained much momentum at the turn from the 1960s to the 1970s, and will be ready to be implemented in the 1970s. They cover an exceptionally broad spectrum and they must be viewed and understood as an entirety.

Many of these new concepts are still in a state of fermentation. Before they can be summarized in subsequent appendices, we should take into account that the wide field of engineering education is the concern of a great many highly qualified people within universities, industry, and government. They represent many kinds of experience and their high qualifications are usually an indication of specialization -- expressing the fragmentation of modern life. It becomes particularly important to bridge the many gaps which exist between the viewpoints of specialists. For this purpose, a brief review of well-documented trends may help to clarify some basic developments:

B.1.1 Historical Perspective

For many decades engineering education has been fortunate to have had a thorough self-examination about once every dozen years. This has been in the form of comprehensive reports which analyzed the overall situation and set up guidelines for future developments. There was the Mann Report at the end of WW I (Ref. 14), the Wickenden Report of 1930 (Ref. 15), the Hammond Reports at the beginning and toward the end of WW II (Ref. 16 & 17), the Grinter Report (Ref. 18) and the Burdell Report (Ref. 19) of the mid-1950s and the Report on Goals of Engineering Education in 1968 (Ref. 20). The increasing emphasis on science and research in engineering education which began after WW II was well on its way in 1955 at the time of the Grinter Report and was clearly endorsed in it. This emphasis on science and research has been the basic characteristic of engineering education for more than two decades.

B.1.2 Report on Goals of Engineering Education (1968)

The Goals Report of 1968 (Ref. 20) recognizes a serious dilemma which had built up over many years. Strong trends tended toward both increasing depth for greater technical proficiency and increasing breadth for a fuller understanding of social and economic forces. With mushrooming developments in science and technology it became extremely difficult to confine these demands within a typical four-year program. As a consequence, it is anticipated in the report that basic engineering education will soon include a fifth year of graduate-level work and it is concluded that the master's degree will be established as the basic degree in engineering during the next decade.

Such a basic baccalaureate plus master's program in engineering is considered to provide the opportunity for added depth and width and it "should help satisfy the widely felt need for increased emphasis on analysis, synthesis, and design at all levels". In addition, diversity in educational practices and offerings and also flexibility in programs will be required to prepare students for a variety of engineering functions and to meet their varied backgrounds. Opportunities must be enlarged on the one hand for the education of engineering technicians and technologists and on the other for advanced engineering education leading to degrees beyond the master's.

The Goals Report also recognizes the need for continued upgrading of faculty and for the fullest possible integration of research with educational purpose of engineering colleges. Besides, it recommends that engineering schools recognize more fully the place of continuing studies as a distinct category in the spectrum of engineering education.

Throughout the Goals Report it is apparent that the orientation of engineering curricula toward science and research, which was greatly stressed in the Grinter Report, has been achieved and is taken for granted. Additional emphasis on synthesis and design is expected to be a by-product of a five-year curriculum. The Goals Report gives a comprehensive survey but some critical comments are made by Henderson in Ref. 21.

B.1.3 Olmsted Report on Liberal Learning for Engineers (1968)

Related to the Goals Report, the report by the Olmsted Committee on Liberal Learning for Engineers, supported by the Carnegie Foundation, was also published in 1968 (Ref. 4). It considers the role of humanities and social sciences in the education of engineers and comes to terms with the larger question of what is the role of technology in the human context. Many practical suggestions are contained in its section on strategies and recommendations.

The report also brings out the very interesting point that for engineering schools the mean percentage of credit hours for

non-technical work has almost reached 20%. This is a goal which was first established by the Hammond Report and has been held constant during intermediate decades. Now, as this goal has practically been achieved, the Olmsted Report concludes and discusses in detail that the return for this investment in time is highly unsatisfactory.

Too many of the courses in social sciences and humanities have all the marks of being just a formal requirement. They often consist of lectures in a field which remains remote and meaningless to the engineering student. What is needed is an emphasis on involvement and on relevance rather than on transfer of information. This means discussions, individualized assignments, feedback, and projects. Some very pertinent remarks are made about the importance of the intellectual climate on a campus and a few examples are given to show what some colleges are beginning to do in this field.

This overall situation allows a conclusion which is somewhat surprising: Liberal learning for engineers basically requires no additional time from our present scientific and technical subjects. It rather requires just a spirit of cooperation and communication and a process of serious rethinking on the part of engineering faculties. Liberal learning can be made an integral and essential part of the education for the professional engineer. There is no reason whatsoever to dread a decline of his technical competence but there is good reason to anticipate his growth in professional stature because liberal education in the proper sense prepares the engineer to assume larger overall responsibilities.

B.1.4 Educational Development Program (1968)

A third study of very fundamental significance to engineering education was also concluded in 1968 and published as a series of reports with Ref. 22 as the final publication. It was undertaken by the Engineering Department of the University of California at Los Angeles under the name Educational Development Program (EDP) and was supported by the Ford Foundation. Based on a decade of intensive work, this project represents an unusually broad spectrum of new viewpoints regarding engineering education and sets up a formidable edifice which integrates many aspects of present-day problems.

The study begins with the basic question about educational objectives which leads to other questions about the kind of person, the kind of society or, more generally, the kind of environment we want to have as the end product of the educational process. The environment depends on decisions which are made by people educated in the professions. The medical profession determines the health environment, the legal profession determines the civil environment, the engineering profession determines the physical environment, etc. Professional responsibilities have much in common, particularly the logic of the professional

decision-making discipline and the need for clear statements about criteria and constraints of value systems. A crisis of the professions is seen in their failure to understand, anticipate, and avert the crises of human affairs. The great challenge to the professions consists of finding solutions for problems which have increased by orders of magnitude and have become too complex and too interdisciplinary for isolated professional action.

Design, defined as an iterative decision-making process, is considered to be not only the essence of engineering but also the common discipline for all professions. Development of the design process into a logical methodology and a formal, teachable discipline represents a major undertaking of the EDP. This is then applied to the design of the educational process in general and to engineering education in particular.

The project was conducted in a clear and purposeful way and was generously funded. Many documents report on its many aspects, reaching from the role and function of engineering in human society to specialized technical subjects. Its lasting influence becomes noticeable only slowly.

B.1.5 New Awareness of Design

In addition to the three basic studies discussed under B.1.2, B.1.3 and B.1.4, and quite apart from the general trend toward science and research, a new interest in teaching the basic aspects of design began to arise in the 1960s and to point toward a renascent interpretation of engineering and design. It took much of a pioneering effort to overcome the traditional image of design which had been characterized by a rather dull and pedestrian routine of teaching machine design closely related to drafting. A new philosophy of design had to be developed -- combining the very different mental processes of creativeness, analysis, synthesis, and decision-making -- while the academic climate with its emphasis on pure analysis was quite hostile toward any attempts to go beyond purely scientific problems.

Important milestones in this development were the first conference on Engineering Design Education at Case Institute of Technology in 1960 (Ref. 23), the second conference at UCLA in 1962 (Ref. 24), the Engineering Conference at Boulder, Colorado, in 1961 (Ref. 25), and the conference on Creative Engineering Education held at Woods Hole, Cape Cod, in 1965 (Ref. 26). A Commission on Engineering Education was formed at the Boulder Conference and financial support for exploring new ideas came mostly from the National Science Foundation. The proceedings of further conferences on Education are given in Ref. 27 & 28.

Starting in 1965, a number of workshops of about four weeks duration were held to stimulate interest and accumulate experience in the teaching of design. The format varied widely depending on the viewpoint of the host institution. Faculty members participated as lecturers or advisers or, in some workshops, as members of a design team. Students ranged, depending on the

course level, from sophomores to graduates. Projects included waste disposal, devices for crippled persons, medical instrumentation, and transportation systems. Emphasis was on team work and in some cases also on producing a prototype. More detailed information is given in Ref. 28.

The essential outcome of these developments was an increasing appreciation for the importance of teaching how to proceed from the theories of the scientist to the practical conclusions of the engineer. It was realized that the student had to be prepared to deal with the real-life complexities which are typical of design.

B.1.6 Interdisciplinary Courses

The basic developments outlined under B.1.5 were carried a step farther by Bollay with courses in interdisciplinary design at MIT and Stanford (Ref. 29 & 30). Complex systems from the field of space engineering were chosen as projects and the students had to use an interdisciplinary approach based on methodologies from system design combined with advanced scientific theories as they performed near the technical frontiers. Close cooperation with industry and research agencies was established by inviting experts for guest lectures and consultation as well as for judging the verbal presentation which accompanied the final report.

Based on this experience, a number of summer workshops were supported by NASA and NSF in the late 1960s to give faculty members the opportunity to become familiar with this approach to design. In summer 1969 four NASA centers cooperated with six universities on such faculty fellowship programs. Typical system design projects were in the fields of spacecraft, aircraft, human factors and atmospheric pollution.

B.1.7 Accreditation of Engineering Curricula

The common denominator for the developments described under B.1.4, B.1.5, and B.1.6 is a new awareness of the importance of design. In 1971 this new trend found its formal recognition by the Engineers' Council for Professional Development (ECPD) which is the agency responsible for accreditation of educational programs leading to degrees in engineering (Ref. 31).

ECPD criteria establish a recognized standard of engineering education. When these criteria were first spelled out in detail in 1955, they included "at least the equivalent of approximately one half of an academic year devoted to engineering analysis, design and engineering systems". This recognition of design was dropped in the early 1960s in order to allow more time for scientific content.

A decisive step toward reinstating design was taken with the revised criteria for 1972-73. Considering the time scale for educational change, the ECPD board "in the year of 1971-72 assessed the decade of the 1960s and took actions for implementation in the 1970s to meet the needs as forecast for the 1980s"

(Ref. 31). These revised criteria recommend for the basic professional level (bachelor's degree) the equivalent of approximately one-half year of design, synthesis, and systems. Requirements in mathematics, basic sciences, engineering sciences, humanities, and social sciences were left unchanged.

For entry into the profession at the advanced level (master's degree), a second half year is expected to be devoted to design, synthesis and systems including a considerable amount of material and treatment at an advanced level not normally associated with the basic level. It should be noted, however, that the American Institute of Aeronautics and Astronautics (AIAA) has expressed reservations about advanced level accreditation and has taken the position to leave the choice of the type of accreditation sought to each individual institution.

It appears that the developments regarding the master's degree will go in dual directions as anticipated in Ref. 32. There should be master's degrees either in science or in engineering and correspondingly doctorates either of philosophy or of engineering. At present only few degrees of master or doctor of engineering are awarded. Ref. 32 projects that by the year 1980 the majority of master's degrees will be in engineering and that by the year 2000 also the D. Eng. will outnumber by far the Ph.D in engineering education.

* * *

Summarizing these considerations, it can be seen that Sections B.1.1 and B.1.2 describe a sequence of studies outlining and guiding the science-oriented developments in engineering education; that Sections B.1.3 and B.1.4 indicate two programs resulting in a new attitude toward engineering education; and that Sections B.1.5 and B.1.6 indicate the slow emergence of design courses as a particularly important aspect of engineering education which finds an official recognition in Section B.1.7.

These three fundamental trends are well-documented and clearly visible. Yet, although no statistical evidence is available, the statement may be ventured that only a small percentage of engineering educators are consciously aware of their full implications. The principal cause is undoubtedly that the majority of present engineering faculties have been brought up as specialists with little interest and experience in design and are so involved in their fields of research and specialization that they have neither the inclination nor the time for broader considerations.

B.2 Emergence of Basic Trends

Development and implementation of new ideas take time and a certain rhythm can be observed. The beginning consists of some pioneering efforts; then comes a slow process of overcoming much inertia; finally, when the motion has gathered considerable momentum, it represents an irresistible force toward general

acceptance of the new idea.

We have experienced the full course of this development in the upgrading of science content in engineering education as shown under B.1.1 and B.1.2. This may justify the application of a past experience toward some conjecture about the future regarding the remaining trends. Considering first the developments in design shown under B.1.5 and B.1.6, they are directed toward the most immediate engineering problems and may be labeled real-life complexities in the broadest sense. The considerations shown under B.1.3 and B.1.4 are concerned with the long-range consequences which technological solutions may have on social and physical environment and with the need for basic value systems. These far-reaching considerations of professional accountability may be called overall responsibilities.

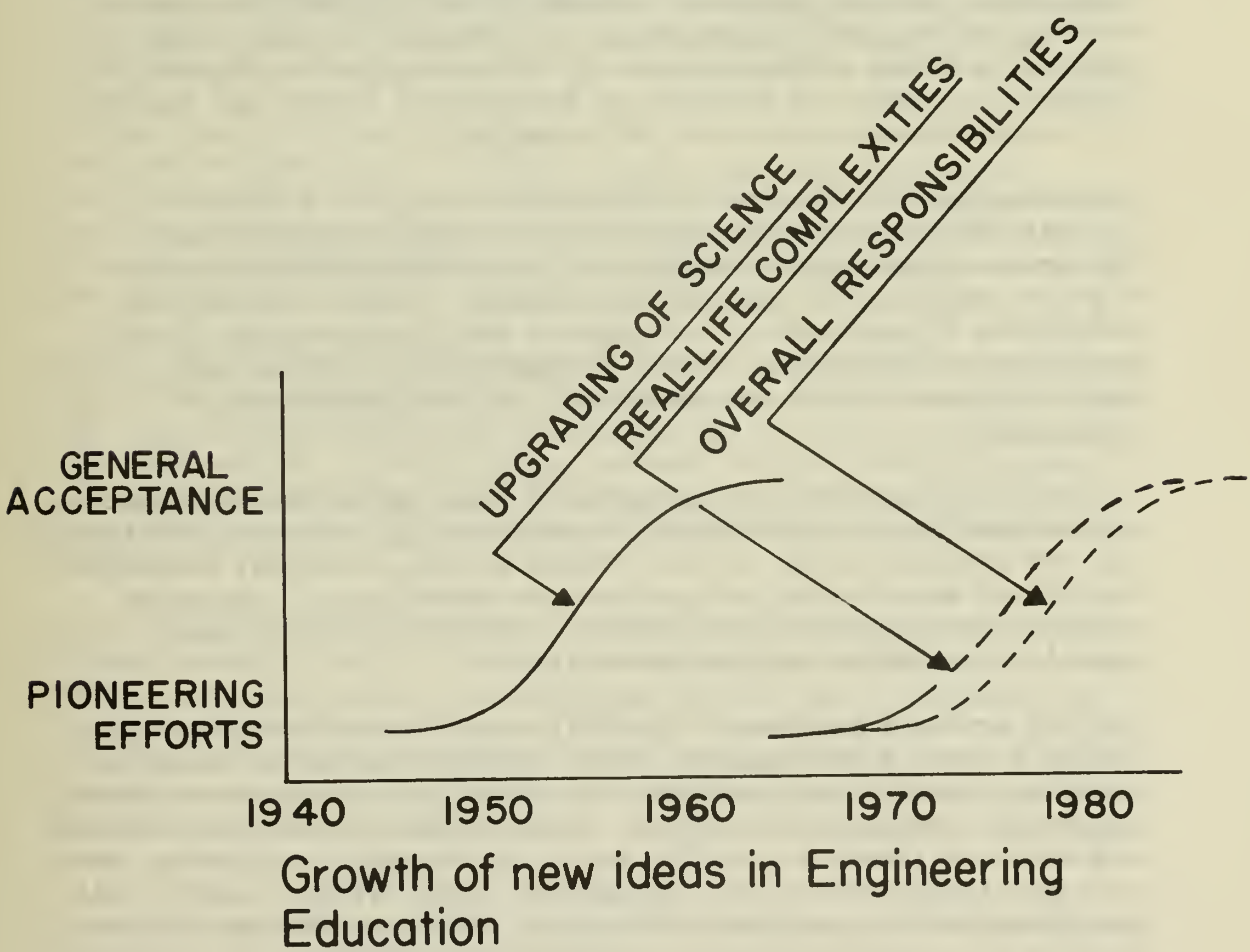


FIGURE B-1

A graphical representation of these trends, as shown in Fig. B-1, is obviously based on extrapolation of limited evidence and the time scale is an easy target for arguments. The main purpose is to identify fundamental trends and to provide a basis for discussion. Each of the three curves signifies an important development in engineering education. The left-hand curve represents an accomplished fact. The two right-hand curves indicate trends which are still in a state of development. The great question is whether it is possible to include an understanding of real-life complexities and of overall responsibilities within the time constraints of an engineering curriculum. A basically affirmative answer is given in the following section -- indicating, however, the problem of time.

B.3 Examples for a New Spirit in Engineering Curricula

Some examples can be shown for the influence of non-traditional ideas on engineering curricula:
The Thayer School of Engineering at Dartmouth College has, throughout its long history, adhered to its original purpose of offering an engineering education to students who have first acquired a broad college education. This requires a minimum of 5 years to obtain the Bachelor of Engineering degree and provides an unusual breadth and depth of education.

The undergraduate program at Dartmouth College is a form of liberal arts education polarized on the engineering sciences. The pre-engineering student obtains his Bachelor of Arts after 4 years, majoring in engineering sciences. This includes prerequisites in mathematics and physics and basic studies in the mechanics of fluids and solids, thermodynamics, fields and circuits, electricity and magnetism, and the properties of materials.

Although this liberal arts program is aimed primarily at preparing the student for advanced study in engineering, it can also qualify him for graduate study in such fields as law, business, economics, industrial administration, physics, or mathematics. The close contact among students with diverse academic interests aids greatly to minimize any provincialism.

For the graduate program of the fifth year the student has the choice between a professional track oriented toward professional practice, design, and environmental planning; or a research track requiring competence in a single field of the engineering sciences and oriented toward scientific posts in industry, government, or research laboratories; or a management track offered jointly with the School of Business Administration. Further advanced studies lead up to Master and Doctor of Engineering degrees.

For the Bachelor of Engineering degree every student is required to demonstrate three proficiencies: firstly in analytical and experimental work in engineering or a relevant field such as chemical processing or bio-medical experiment design, or automatic

controls, or digital computation; secondly in creative design; thirdly in the economic analysis of an engineering problem.

The Thayer School has a Partners and Associates Program for close cooperation with business and industry. Participating companies contribute annual grants and a working relationship is established as they are invited to conferences and as they furnish problems which might serve as design projects. Frequently problems occur in industry which cannot be followed up due to lack of manpower, time, or funding. Such problems can be extremely stimulating for design courses when an engineer from industry serves as an advisor and brings industry, faculty, and students in close contact.

Design is considered to be the characterizing ability of an engineer. The first design course taken by prospective engineering students occurs in the first term of the sophomore year and is entitled Introduction to Engineering. Teams of students are working on design problems and lectures are devoted to principles of design. Besides, since Dartmouth recently adopted year-round operation, every undergraduate is encouraged to spend one or more off-campus terms in activity related to his academic program.

In the graduate program of the fifth year all students are required to complete a 3-course design sequence representing one-third of the total work during the year. The design problems are real and significant problems originating from industry or government agencies and allow the student to display innovative and professional design abilities.

Worcester Polytechnic Institute recently introduced an engineering and science curriculum with a new focus and a new structure. The WPI Plan is directed toward understanding both the technology and its implications. Seventy-five percent of the learning process is built around traditional study methods. The other 25% uses real-life problems as course material for independent study and projects.

Much flexibility is provided by a calendar which consists of two 7-week terms in fall, a 3-week intersession in January, two 7-week terms in spring, and a 7-week Summer Session which can serve as an optional fifth term for any student who wishes it. The length of time needed to get a degree is not fixed. It depends on the individual student, his background, his motivation, the type of his program, and so forth and may take somewhat less or more than four years.

Each student has the responsibility for developing, with faculty guidance, an individualized academic program to fullfill the degree requirements. In addition to regular coursework the student participates in various capacities in half a dozen projects and tutorials, each taking about one-third of his work in any given term. Finally, he has to complete two "independent studies" projects, under the individual guidance of a faculty member, each equivalent to a full-time seven-week term.

One of these "independent studies" is in the student's major field of interest; the other normally relates the student's major to social science and humanistic problems. They are carried out either on campus or off campus at Internship Centers established at governmental agencies, industrial corporations, and private laboratories. The projects are not routine but are concerned with solving real problems in their real-life settings. Typical problems are the abatement of a pollution problem at a factory or the testing of a preproduction piece of equipment.

To obtain the degree, the student has to demonstrate his competence through projects, tutorials, independent study, and a comprehensive evaluation. The latter consists of a single- or multi-answer problem and may take several days, with free access to reference material, other students, and faculty. Understanding of methods, processes, resources, and underlying principles and theories are evaluated.

There are three different grades: acceptable, acceptable with distinction, or not acceptable. The student's transcript contains a description of his qualifying projects, together with comments and an evaluation by his faculty advisor. For transfer to another school, this can be converted to a semester-hour, quality-point system.

The three-week Intersession in January consists of three one-week seminars. About 150 different topics are available for study, ranging across all the departments and various interdisciplinary areas. Outside resource people are brought to the campus and an atmosphere prevails which is different from the normal routine of classes and studies.

The WPI Plan provides unusual flexibility for individualized programs, with emphasis on the interaction between engineering and society. The degree is awarded upon demonstrated competence and the length of time depends on the student's rate of learning, his program, and on the use he makes of the optional Summer Session. This eliminates the lock-step feature of education and may be to the good of the gifted as well as the slower student.

Harvey Mudd College at Claremont, California was founded in the late 1950s. It is a college of science and engineering which has pioneered since its beginning a philosophy that an engineering education has to be combined with a solid background in not only the physical sciences but also in humanities and social sciences. To develop a clear understanding of the impact of the engineer's work on the rest of society, humanities and social sciences occupy an unusual 35% of all course work in the four-year undergraduate curriculum.

The standards of admission are high and all students must be deeply dedicated to mathematics and science. With this premise, the freshman year presents a common basis for all students and consists of only three main courses: natural philosophy, calculus, and

"quest for commonwealth".

Natural philosophy combines physics and physical chemistry and contains stoichiometry, thermodynamics, bonding, equilibrium, kinetics, dynamics, linear and angular momentum, work and energy, harmonic motion, and laboratories in chemistry and physics. Students who are given advanced placement take special theory of relativity instead of some of the other subjects.

The course in calculus develops not only the subject matter but is also intended to develop mathematical maturity for understanding modern, abstract mathematics. Emphasis is also on application of calculus techniques as needed in natural philosophy and an introduction to computer programming and the use of computers in problem solving.

Quest for commonwealth is concerned with fundamental problems of society and individual. Sources and nature of human values and the relevance of these values to problems of an advanced technological civilization are studied. In the second semester a Freshman Year Project introduces techniques for solving open-ended problems as students work in small teams on real problems taken from the surrounding community.

The sophomore year brings the transition from pure sciences to engineering science courses. The engineering curricula are based on the premise that the primary function of engineering is design. A three-semester series of courses in system engineering begins in the sophomore year and a three-semester "engineering clinic" begins in the junior year. The name Clinic implies an analogy with the medical profession. Teams of professors, adjunct professors from industry, and students work together as senior and junior colleagues on real-life problems which are submitted and funded by industry. A program for the Master of Engineering degree provides additional depth in design and management.

The emphasis of the Harvey Mudd engineering curriculum on both humanities and design, combined with a rigorous mathematical background, is quite interesting. This provides an unusually broad perspective and thorough understanding of the overall technological world -- and a challenge to the gifted and motivated student.

APPENDIX C

AEROSPACE ENGINEERING EDUCATION

C.1 Aerospace Faculties

Aerospace curricula have been particularly vulnerable to the "knowledge explosion" after WW II and new subject matters have mushroomed. Well-established fields like flight performance and propulsion have expanded to cover a spectrum from VTOL to orbital velocities and to include subsonic, transonic, supersonic, and hypersonic flow. Flight structures, for instance, contain the highly specialized subdivisions of finite element methods, plates and shells, elasticity and plasticity, structural dynamics, and mechanics of composite materials. New fields like gas dynamics, aerothermoelasticity, guidance and control, or computer methods had to be incorporated in addition to the many new spcializations for space flight.

As a result, aerospace faculties at least as much as other engineering faculties became preoccupied with upgrading the scientific content of curricula. During the last two decades new faculty members with a specialized research background but without aeronautical engineering experience slowly replaced others with broad practical experience who often held only a master's degree. This trend toward research has a self-perpetuating character. Good research facilities attract more research. Students searching for an elective will be steered toward specialization and research rather than toward design. Graduates will be allured toward doctorate, research, and teaching but not so much into industry.

The research-oriented climate at universities developed rapidly during the 1950s and 1960s, nurtured consciously by academic policies and supported by government contracts. Outstanding accomplishments were achieved. Yet a price had to be paid. The well-established traditional balance between science and engineering within engineering faculties was disturbed. A spirit of science as a goal in itself became dominant. This was in step with general developments where engineering was employed in the service of scientific exploration. With this combination outer space was conquered and our insight into the laws of nature was advanced greatly. Our society was willing to provide the funds and aerospace faculties prepared the foundation for this development.

A change began to take place in the early 1970s. The widely visible goal of a lunar landing had been reached at the same time as grave doubts about the general course of human events began to cause serious unrest at universities. Our society became weary of underwriting scientific exploration per se and began to ask questions about problem definition, need analysis, and optimization of technological means which are in the domain of engineering rather than science. These questions have to be answered within an overall context for which a purely research-oriented

outlook is not sufficient. It takes no gift of prophecy to recognize that the pendulum is swinging back from an over-reliance on science toward engineering but this is not yet noticeable in aerospace curricula (see also App. H).

C.2 Typical Aerospace Curricula

Typical aerospace curricula of 1972-73 do not show any basic changes compared to preceding years. However, it is difficult to talk about a single "typical" aerospace curriculum among the many ECPD-accredited curricula offered in the United States (see App. E). Therefore, five widely recognized curricula covering a wide spectrum have been selected for Appendix D where a brief outline is given for each.

These five aerospace curricula at different universities were chosen as representing five well-established trends within the spectrum of engineering education. M.I.T. enjoys a particular reputation for excellence and offers both undergraduate and graduate aerospace curricula. Stanford has a similar reputation and a similarly wide range of research activities but provides aerospace curricula for graduate students only. The University of Washington provides a design course in close cooperation with a major aerospace manufacturer. Cincinnati University has pioneered co-operative programs where students work in industry. California Polytechnic State University at San Luis Obispo offers an unusually close interaction between theory and application.

Some reflection upon the survey given in Appendix D will lead to several basic observations.

a. Accreditation by the Engineers' Council for Professional Development (ECPD) guarantees a recognized professional quality for an undergraduate aerospace curriculum (see App. B.1.7). The criteria used for accreditation are designed to be flexible enough to permit the expression of an institution's own individuality and ideals. They are intended to encourage and stimulate and not to restrain creative and imaginative programs.

b. Beyond these basic criteria an appreciable range of educational levels and climates exists. There seem to be two main parameters: firstly the standards of admission for entering freshmen which determine the level of undergraduate courses and secondly the quality of laboratory facilities and research projects which determine the atmosphere for graduate work.

c. A large number of courses providing a wide range of specializations or individually tailored studies is typical of aerospace programs. Some curricula include many free electives and allow the student much freedom to design his own program in consultation with his faculty advisor. Others offer the choice between more closely prescribed options with fewer free electives.

d. Courses in aircraft design are provided in the curricula selected for Appendix D but they are partly optional and not supported by other courses. Except for Cal-Poly, the curricula are clearly science-oriented, with the emphasis on analysis and research rather than on design.

e. The emergence of design, synthesis, and systems as a particularly important aspect of engineering education is not noticeable at all in the great majority of aerospace curricula. It should be noted that the revised ECPD criteria have not been effective yet in these curricula.

APPENDIX D

SELECTED AEROSPACE CURRICULA

The following brief descriptions are based on catalogs for the academic year 1972/73. Numbers of faculty and graduates are in accordance with Appendix E.

Massachusetts Institute of Technology (M.I.T.) has a Department of Aeronautics and Astronautics which offers more than 20 undergraduate and about 70 graduate semester courses. The department has 42 faculty members. Forty-six Bachelor of Science degrees in Aeronautics and Astronautics, 56 degrees of M.S. or Engineer in Aeronautics and Astronautics, and 14 doctorates of science or philosophy were awarded in 1971/72. The academic year consists of two semesters with 14 weeks of classes each and an intermediate period of 3 1/2 weeks in January for independent activities.

The department has five divisions: Mechanics and Physics of Fluids; Structures, Materials, and Aeroelasticity; Instrumentation, Guidance and Control; Energy Conversion and Propulsion; and Aeronautical and Astronautical Systems.

Departmental research is conducted in the Draper Laboratory for Guidance and Control and in the laboratories for aeroelastic and structures research; aerophysics; flight transportation; fluid dynamics; gas turbines; laser systems; man-vehicle research; measurement systems; plasma physics; space propulsion; and VTOL technology.

The undergraduate program is characterized by the high standards of admission at M.I.T. and the correspondingly high level at which the educational program is set. The student must decide not later than the end of the sophomore year whether he wants to obtain his B.S. in aeronautics and astronautics. Mathematics, physics, and chemistry courses occupy 23% of the program; humanities 20%; engineering sciences* 36%; and free electives 21%. The elective freedom can be used by the student during the third and fourth year for specialization in a particular field as represented by the five departmental divisions or he can, in consultation with his advisor, enroll in a variety of subjects to maintain breadth in his course of study. A one-semester course in either flight vehicle or space systems engineering gives the senior student an opportunity to apply fundamental approach and compromises inherent in the design process to performance, stability, and control. Other design-oriented courses would have to be arranged within

*Required courses consist of mechanics of solids, structural mechanics, thermodynamics and statistical mechanics, science of materials, introduction to electronics, dynamics, aerodynamics, experimental projects, propulsion, principles of either automatic control or flight guidance, and either flight vehicle or space system engineering.

electives.

Graduate study in any of the five divisions of the department is based on additional undergraduate preparation in the field of specialization. The broad scope of research efforts and laboratory facilities within the department provides outstanding opportunities for students to participate in meaningful research projects. Fields of endeavor can be either specialized or fairly general. A graduate course in Advanced Systems Engineering is concerned with a typically complex aerospace systems design project along the lines mentioned in Appendix B.6. A thesis is required for the M.S. degree.

Stanford University has a Department of Aeronautics and Astronautics which offers over 70 quarter-courses but has no undergraduate program of its own. The department has 18 faculty members and awarded 42 M.S. or Engineer degrees, and 22 Ph.D. degrees in 1971/72. The academic year consists of three quarters with 10 weeks of classes each.

Departmental research activities cover a wide range and are conducted mainly in structures laboratories; guidance, control, and instrumentation laboratories; radiative gas dynamics laboratory; and the aerophysics laboratory for plasma research.

The undergraduate program of the School of Engineering at Stanford University provides much freedom for combining a liberal education with a specialized study. It leads to a B.S. degree which contains 25% mathematics, physics, chemistry, and biology; 16% humanities and social sciences; 37% engineering sciences; and 22% free electives. A proper distribution of the engineering science courses has to ensure engineering breadth and depth and a functional balance between analysis, synthesis, experimentation, and communication. Breadth is provided by choosing courses in not fewer than five of eight categories of engineering*. Depth is provided by choosing a coordinated series of courses in a well-defined field of majors -- either within a department or as interdisciplinary majors or as innovative majors. One of the interdisciplinary majors includes five courses given by the Department of Aeronautics and Astronautics.

To obtain an M.S. degree in Aeronautics and Astronautics within three quarters, entering graduate students are expected to combine an aeronautical engineering background with a B.S. degree in engineering, physical science, or mathematics, or an acceptable equivalent. Two curricula are offered, one oriented toward the sciences, the other emphasizing engineering. However, the

*These eight categories are: mechanics of solids and fluids; electromagnetism, electric circuits and devices; thermodynamics; materials science and properties; logic and computer systems; systems analysis and control; mass and energy transfer; decision processes, engineering economy, and design.

only difference in requirements is that the engineering curriculum has 3 units less of mathematics and 3 units more of aerospace-related specialization than the science curriculum. No thesis is required for the M.S. degree.

Sequences in engineering analysis of flight vehicles, analysis of aerospace structures, introduction to aerospace systems synthesis and analysis, structural dynamics and aeroelasticity, thin shell analysis, mechanics of composite systems, aerospace structures laboratory and some others, extend through all three quarters of the academic year. A course in engineering systems design along the lines mentioned in Appendix B.1.6 is offered at Stanford outside the Department of Aeronautics and Astronautics.

Graduate students who obtained their B.S. degree at Stanford have had courses in synthesis. Design-oriented courses in the graduate program are optional.

University of Washington, Seattle has a Department of Aeronautics and Astronautics which offers almost 40 undergraduat and over 60 graduate quarter-courses. The department has 20 faculty members and awarded 62 B.S. degrees, 17 M.S. degrees, and 5 Ph.D. degrees in 1971/72. The academic year consists of three quarters with 10 weeks of classes each.

The undergraduate program in aeronautics and astronautics is entered at the beginning of the junior year after the previous two years are spent in general courses. It leads to a B.S. degree which contains 23% mathematics, physics, and chemistry; 17% humanities and social sciences; 7% functional techniques; 9% general engineering sciences; 33% aerospace-related courses; and 11% free electives. The functional techniques contain the following five fields: graphics; written and oral communication; computational technology; design and synthesis technology; and laboratory techniques. The general engineering sciences contain materials, discrete mechanics, continuum mechanics, linear systems, thermodynamics, and air-water interface vehicles.

The aerospace-related courses in the junior year consist of three one-year sequences in aerodynamics, structural analysis, and junior laboratory with additional one-quarter courses in orbital mechanics, flight mechanics, and aeroelasticity. In the senior year the student chooses 9 courses from the following eight fields: gas dynamics; design; laboratory projects; structural mechanics; flight mechanics; space mechanics; propulsion; and structural dynamics and aeroelasticity. In at least two of these fields the student is expected to follow a one-year sequence of courses. The three-quarter sequence in aircraft design deserves special mention because it is given in close cooperation with the Boeing Company.

The graduate program requires additional breadth through study of a variety of subjects and depth through intensive study of a chosen field of specialization. A thesis is optional for the M.S. degree and additional course work serves as a substitute.

The University of Cincinnati has a Department of Aerospace Engineering which offers about 50 undergraduate and about 70 graduate quarter-courses. The department has 14 faculty members and awarded 41 B.S. degrees, 23 M.S. degrees and 5 Ph.D. degrees in 1971/72.

A cooperative program was inaugurated by the College of Engineering as early as 1906 as an original study experience. Now known as the Professional Practice Program, it also determines the baccalaureate aerospace engineering curriculum. For the B.S. degree students are required to have 12 quarters (127 weeks) of regular courses and a minimum of 4 quarters (50 weeks) of related practical experience. A maximum of 92 weeks of practical experience can be incorporated in the given five-year curriculum. The university makes no guarantee as to practice assignments and earnings but does make every effort to place students to their best educational advantage. There are nearly 1000 cooperating firms and agencies.

The curriculum is organized so that the three quarters of the freshman year and the final three quarters of the senior year are not interrupted by professional practice. What corresponds to the conventional sophomore and junior years has been distributed over three years of study interspersed with practical experience. As a consequence, there is a freshman year, second year, third year, fourth year, and senior year.

The freshman year is the same for all engineering curricula. In the aerospace curriculum increasing emphasis is given to aerospace subjects in subsequent years. The B.S. degree contains 28% mathematics, physics, and chemistry; 14% humanities and social sciences; 15% general engineering sciences; 36% aerospace-related courses; and 6% technical electives offered by aerospace engineering. Departmental laboratories in structures, fluid dynamics, and propulsion are, of course, an integral part of the over-all course structure. A one-quarter senior course in aerospace design gives an introduction to design concepts.

The graduate program emphasizes in general one of the following areas: dynamics and control systems, fluid mechanics, propulsion systems, or structural mechanics. Both thesis and nonthesis M.S. programs are available.

California Polytechnic State University, San Luis Obispo, Calif. has a Department of Aeronautical Engineering which offers over 40 undergraduate courses. It has 9 faculty members and awarded 42 B.S. degrees in 1971/72. The academic year consists of three quarters of ten weeks each.

The curriculum in aeronautical engineering represents an interplay between theory and application hardly found at other universities. It emphasizes analysis in conjunction with the practical engineering aspects of designing, testing, and manufacturing. The four-year B.S. program prepares the student for immediate entry into the practice of aeronautical engineering in industry.

During the freshman year the student takes a sequence of three quarters in each of three fields: mathematics, aerospace fundamentals, and manufacturing processes. The sequence in aerospace fundamentals serves as an introduction to the engineering approach toward problem-solving and analysis of experimental data, with emphasis on individual projects and do-it-yourself. The sequence in manufacturing processes includes turning, milling, drilling, brazing, gas welding, arc welding, casting, forging, and non-destructive testing, with emphasis on laboratory work. The freshman year also introduces the student to applied descriptive geometry in the first quarter and digital computer applications in the last quarter in addition to the mathematics sequence.

The sophomore year provides sequences in mathematics, engineering mechanics leading into strength of materials, general physics continued from the freshman year, and general chemistry. Additional courses include electric circuit theory and solution of engineering problems by means of analog computers.

During the junior and senior years the courses consist of aerothermodynamics, electronics, aerodynamics, stability and control, stress analysis, mechanical vibrations, advanced structures, gas dynamics, propulsion, and engineering science and technical electives. A two-quarter design course and an additional two-quarter senior project are included in the senior year and place emphasis on both analysis and design. Besides, throughout the four-year curriculum, non-technical subjects account for about 18% of the total courses.

APPENDIX E

U.S. AEROSPACE-ORIENTED CURRICULA ACCREDITED BY ECPD

The following list includes all U. S. aerospace-oriented curricula leading to degrees in engineering and accredited by ECPD in 1972 (Ref. 31).

Numbers of full-time faculty, student enrollment, and degrees granted are based on Ref. 33. Numbers of faculty and enrollment refer to the beginning of the fall term 1972-73. Degrees granted refer to the academic year 1971-72.

The titles used for aerospace-oriented curricula include: Aeronautical Engineering, Aeronautical and Astronautical Engineering, Aeronautical Engineering and Astronautics, Aeronautics, Aeronautics and Astronautics, Aerospace Engineering, and Aerospace Engineering Sciences (Ref. 31).

With respect to the numbers it should be realized that the period of the early 1970s represented a period of transition where freshman enrollments in many cases dropped to less than 50% of the peak figures around 1968. In 1972 this had yet little influence on the number of degrees granted.

* Numbers adjusted for aerospace where departments have been merged (based on personal information).

** Merged departments, no breakdown data available for aerospace.

*** No data given in Ref. 33.

		Enrollments		Degrees Granted		
	Faculty	Undergrad.	Graduate	Undergrad.	Master's or Engin.	Doctorate
University of Alabama University, AL 35486	8	37	1	15	6	0
University of Arizona Tuscon, AZ 85721	12	106	32	11	18	1
Auburn University Auburn, AL 36830	13	50	21	41	0	0
Boston University Boston, MA 02215	9	21	11	18	2	0
Polytechnic Inst. of Brooklyn Brooklyn, N.Y. 11201	11	265	36	48	7	2
Brown University Providence, R.I. 02912				1		
Calif. Inst. of Technology Pasadena, CA 91109	16	-	42	-	26	7
Calif. Polytechnic State Univ. San Luis Obispo, CA 93401	9	169		42		
Calif. State Polytechnic Univ. Pomona, CA 91768	5	125	3	32		
Calif. State University *** San Diego, CA 92115						
Catholic University of America* Washington, D.C. 20017	5	11	31	3	8	2
University of Cincinnati Cincinnati, OH 45221	14	144	61	41	23	5
University of Colorado *** Boulder, CO 80302						
Cornell University Ithaca, N.Y. 14850	8	-	21	-	7	6
University of Florida Gainesville, FL 32601	8	43	12	18	5	2
Georgia Inst. of Technology Atlanta, GA	33	254	83	76	42	10
Illinois Inst. of Technology** Chicago, IL						
University of Illinois Urbana, IL	19	202	38	71	10	4
Iowa State University Ames, IA	16	265	17	63	4	4
University of Kansas Lawrence, KS	6	83	5	39	5	0
University of Maryland College Park, MD	7	89	39	25	2	1
Massachusetts Inst. of Techno. Cambridge, MA	42	53	145	46	56	14
University of Michigan Ann Arbor, MI	33	160	50	95	12	8

		Enrollments		Degrees Granted		
	Faculty	Undergrad.	Graduate	Undergrad.	Master's or Engin.	Doctorate
University of Minnesota Minneapolis, MN	18	115	22	51	7	3
Mississippi State University State College, MS	11	61	24	14	5	0
State University of New York Buffalo, N.Y.		23	14	8	1	1
New York University Bronx, N.Y.	13	57	39	19	13	9
North Carolina State University* Raleigh, NC	8	84	28	30	1	4
Northrop Inst. of Technology Inglewood, CA	7	126	8	38	1	-
University of Notre Dame Notre Dame, ID	12	76	9	31	8	3
Ohio State University Columbus, OH	13	164	85	61	12	3
Oklahoma State University * Stillwater, OK	4	33	6	17	1	1
University of Oklahoma Norman, OK	6	51	13	23	5	1
Pennsylvania State University University Park, PA	16	77	40	43	5	4
University of Pittsburgh Pittsburgh, PA		25	0	14	0	0
Princeton University ** Princeton, N.J.						
Purdue University * West Lafayette, IN	26	224	68	116	31	9
Rensselaer Polytechnic Inst. Troy, N.Y.	5	30	9	15	12	1
University of Southern CA Los Angeles, CA	13	43	49	11	15	6
Stanford University Stanford, CA	18	-	135	-	42	22
Syracuse University ** Syracuse, N.Y.						
University of Tennessee * Knoxville, TN		69	47	15	4	5
Texas A & M University College Station, TX	14	159	22	62	6	0
University of Texas Arlington, TX	8	141	6	31	2	0
University of Texas Austin, TX	20	136	70	52	25	10
Tri-State College *** Angola, IN						

	Faculty	Enrollments Undergrad.	Enrollments Graduate	Degrees Granted Undergrad.	Degrees Granted Master's or Engin.	Degrees Granted Doctorate
U. S. Air Force Inst. of Techno. Colorado 80840	43	139	-	19	-	-
U. S. Air Force Inst. of Techno. Wright-Patterson AFB, OH		-	184	-	61	8
U. S. Naval Academy Annapolis, MD	11	125	-	53	-	-
U. S. Naval Postgraduate School Monterey, CA 93940	21	-	124	11	70	1
Virginia Polytechnic Inst. Blacksburg, VA	10	111	51	34	4	8
University of Virginia Charlottesville, VA	14	62	20	27	3	2
University of Washington Seattle, WA	20	69	75	62	17	5
West Virginia University Morgantown, WV	9	52	17	27	4	0
Wichita State University Wichita, KS	12	68	30	27	6	2

APPENDIX F

AIRCRAFT DESIGN -- AS TAUGHT TRADITIONALLY

F.1 General Survey of Design Courses

Courses in the design of flight vehicles have been taught for decades. They have usually provided the capstone for an aeronautics curriculum and have served as a bridge between learning and doing. Students are to go through the actual experience of having to consider the main aspects of a design and to make the necessary compromises and trade-offs. As a consequence, they gain self-confidence and a more mature outlook toward the practice of engineering.

Aircraft design is a dynamic and versatile subject. To do justice to it, a design course must be arranged around a project which is realistic and well chosen. The project should stretch the student's capabilities without getting beyond his firm grasp, provide opportunities for team work as well as individual responsibility, include several disciplines, and necessitate a combination of fundamental principles and practical application. Full responsibility for the design must rest with the students and the role of any faculty members is strictly advisory. Final reports and oral presentations must be of professional quality.

It appears important to provide a climate for the design course which resembles the conditions under which design actually takes place in industry. Quite frequently teams of 4 to 8 students are formed representing the kind of work done by a preliminary design group. Often they are set up in competition with each other, much like different companies working on the same given problem. Each team chooses a project leader who assigns individual responsibilities -- preferably on a rotating basis so that a wide spread of experience is gained.

With increasing complexities of design and decreasing numbers of faculty with broad design experience, it often becomes advisable that several faculty members and engineers from industry should be available for guest lectures and consultation. Yet responsibility for the design course continues to rest with a principal faculty advisor who must have a broad background and industrial experience. There is much organizational work necessary to prepare such a design course, requiring at least half the time of the principal advisor during the term preceding the design course.

A traditional design course should extend over a sequence of at least two quarters but there never seems to be enough time for all the things which ought to be done. Typically the project may consist of submitting a proposal in response to an RFP (request for proposal). This includes as a first part overall design

considerations like parametric studies, general layout, weight, performance, and cost estimates, aerodynamic characteristics for stability and control and for structural loads, and critical loading conditions. As a second part, considerations are directed toward the design of components, e.g. load-carrying structure, control systems, high-lift devices, air intake ducts, etc., where individual assignments are given to students to consider special problems typical of design. It is particularly the coverage of this second part which has almost faded into oblivion due to the gap which has developed between universities and industrial practice.

Lectures or seminar discussions are coordinated with the phase of design on which the students are working. They provide not only a guideline for the design work to be performed but also put the subject into the proper overall perspective and tie up loose ends which had not been covered in regular courses. Typical topics of more general interest include recent developments, case studies based on accident investigations, computer-aided design, general aspects of structural design criteria, production design, corrosion, reliability and safety, structural materials, fatigue design and fail-safe concepts, etc.

Two examples may be mentioned to indicate the wide range of existing possibilities to deal with these subjects: At Stanford University for a good number of years the design course has been taught by a visiting professor coming from industry with extensive recent design experience, usually staying at the university for two years. At the University of Washington in Seattle, the design course is taught in close cooperation with the Boeing Company. Boeing design experts in various subjects under discussion are temporarily and successively assigned by the company to act as consultants for the design course and field trips are arranged for combined lectures and demonstrations to show the students what the "real world" looks like in these fields.

F.2 Critical Comments

A slow development toward more emphasis on needs analysis, decision-making, and optimization can be observed. As pointed out by Rodenberger in Ref. 34, a request for a proposal, although it is the basis for a design, is in itself the result of an iterative process of problem definition which is based on market needs and statistical data indicating the relationship between engineering project and needs of society. It may take the first few weeks of the design course to formulate such an engineering statement of the problem but it will be a worthwhile experience for the student.

Some harsh charges against courses in aircraft design are made by Hale in Ref. 35. Unfortunately, these charges contain much truth. The cost of a good design course in terms of time and effort expended by faculty and students is unusually high. Unless these considerable amounts of time and effort are spent, the objective of the course is not attained. The student must feel free to

concentrate on a design project and "live with it". The faculty member must take the time to follow closely the students' work, to answer questions even if they may sidetrack him, and to discuss any ideas a student may have. Interdisciplinary coordination is required. A situation where the student is simultaneously under pressure of time due to other requirements or where a faculty member has his mind on publishing research results as a more profitable way toward professional recognition should not be tolerated.

It is seen that a course in aircraft design along traditionally developed lines is a major undertaking. The minimum requirement is a faculty in close contact with the aerospace industry, and the examples given in the last paragraph of Section F.1 indicate the kind of resources which are desirable. There are, however, new aspects coming up which go far beyond traditional concepts and which will be considered in Appendix G.

* * *

A basic problem of design education is to bridge the gap between theory and practical application. It is quite worthwhile to remember how successfully this was done half a century ago in Europe, particularly in Germany and Poland. Throughout the 1920s and early 1930s, while principles of aerodynamic refinements and lightweight structures were developed, student groups did pioneering work in their application. These students translated theoretical knowledge into the practical experience of developing gliders and sport planes of small horsepower. They used their own initiative, substituting hard work and much enthusiasm in place of financial resources. They conceived, designed, built, and flew planes of an outstanding technical elegance and established highest standards of performance in challenging competitions.

All this took place in a rare spirit of combining science, engineering, craftsmanship and action with a youthful longing for the wide blue yonder. Such a spirit cannot be created synthetically but its ingredients can still be found in any good design course. What used to be the challenge of altitude or speed is replaced now by the challenge of outer space or of solving the problems of human society on our own planet.

APPENDIX G

EXPANDING CONCEPTS IN DESIGN

G.1 The Role of Design

The preceding appendices are concerned with the academic aspects of present engineering curricula at universities. Now let us look at the practical aspects of aircraft engineering in order to understand the function of design in the aircraft industry and correlate it with aeronautics curricula. We must start with some basic observations which cannot be quantified easily but which are evident enough so that they can be discussed clearly. It will be worthwhile to go into some details because the subject is at the root of the problems of design.

The image of design has undergone considerable changes within a rather brief period. As a consequence, there is a lack of clearness, or even a good deal of confusion, about some very basic questions. Is the designer at the drawing board in the process of being superseded by a combination of analysis, computerization, and system engineering ? Indeed, what is the role of design and who is the designer ?

After a long period of silence in this field, design has been the subject of a good many books published in recent years. Some of them are given in References 5 to 13 but none of these books have quite the same definition of design and it appears worthwhile to list some typical interpretations as done in Appendix A.2.

Some of these definitions sound rather dry and dull. Yet in many of the references it is pointed out persuasively that the designer has to have imagination, inventiveness, and a good many other intangible qualities as well as an analytical mind and scientific understanding. Those qualities which go beyond purely analytical capabilities distinguish the good designer. The full implications are brought out clearly in Ref. 36 where Blumrich traces the imbalance between the two facets of engineering education: while analytical disciplines are taught to the very borders of our present knowledge, design is practically left to develop according to the natural ability of the individual. As a consequence, we have capable analysts who can make almost any design work, albeit laboriously and expensively, but we do not really appreciate the need for talented designers who can provide a simple, elegant, and economic design in the first place. Analysis is held in high esteem while the drawing board has become a negative status symbol!

This stark confrontation of design and analysis calls for some qualifications in order to avoid misunderstandings. It refers to a general image of design which has developed since the 1950s. Due to the strong emphasis on education in analytical methods, a certain snobbishness developed at universities, considering the designer to be just a glorified draftsman. Contrary to this general image,

however, practical experience in industry has brought about a new awareness of the pivotal importance of the designer. This discrepancy between general image and practical reality still obscures and conceals the role of design. It goes back to the basic questions of definition and interpretation (see App. A).

Responsible positions in design are held mostly by the "old breed" of designers who have had some 20 years of experience, were educated before the strong emphasis on analytical methods had developed, and gained their basic experience during the 1950s when industry had an abundance of new projects providing challenge and variety to the designer. It appears that a void is coming up after this generation. Many a promising younger engineer has been dissuaded from choosing a design career because design did not appear as glamorous as analytical work and advancement has been slow. Even among those who started out in design, the turnover away from it has been unduly great.

There is an outspoken anomaly in this situation. Industry needs both designers and analysts. The need for analysts has been clearly recognized and the examples of engineering curricula in Appendix D indicate the thoroughness of preparation offered by our universities in this field. Yet an indolence toward design has developed on the academic level as a side effect during the last two decades. The consequences can be recognized only when we are fully aware of this situation as it developed at the universities during the 1950s and 1960s and as it is described in Appendices B, C, and H.

It appears that a basic change is taking place and that engineering design is about to be recognized again -- just as it was in earlier days of engineering -- as the central responsibility concerned with all aspects of a project, from original concept to final hardware. This basic responsibility was never quite abandoned but it became increasingly diluted by specialists who took over parts of it. Structures analysts, process engineers, production engineers, value engineers, system analysts, and many others have developed a degree of specialization which makes it hard for the designer to stay on top and communicate with them.

Typical designs of any complexity are the product of team work among specialists. To guide and integrate a team requires much more than the traditional design qualifications of creativeness and engineering judgment. Let us begin with considering the subject of integrating many specialized fields. This involves a fine interplay between analysis and synthesis. Analysis approaches a problem by resolving it into its component parts and investigating each one separately. Synthesis is concerned with joining and fusing the components into a new functional entity. Both analysis and synthesis belong inseparably together and form the core of the design process.

With the increasing sophistication in analytical methods, the prestige of the scientific analyst soared high and he obtained a decisive role in design. Subsequently it was realized that this

prominence of analysis has frequently been at the expense of synthesis. When a remedy was promised by system engineering with a systematic approach to planning and designing complex systems, sometimes utilizing sophisticated mathematical methods, it appeared as if design was destined to be squeezed in between analysis and system engineering.

However, both analysis and system engineering provide advanced methods on a rather abstract level. Analysis is usually based on simplifications to make a problem mathematically tractable. System engineering is based on an approach which idealizes and simplifies relationships in form of a model for planning and designing complex systems. Such simplifications result in abstractions.

Design, on the other hand, is concerned with down-to-earth problems, either on a purely technical level or interacting with non-technical considerations. The designer has to understand the interaction of practical problems as well as the specialist's viewpoint. The analyst's education does not provide the needed width of perspective and the system engineer's education does not offer the needed depth of perception. Each one is a specialist indispensable for a complex design. Yet neither one of them is prepared to fill the designer's shoes.

* * *

A fragmentation of viewpoints has developed between analyst and designer due to different educational backgrounds. It takes many years of close cooperation between them to bring about an understanding for the other's outlook. This is highly regrettable because both are interdependent.

For instance, an airframe design is the outcome of a complex computer program with the geometry created on the screen of the cathode-ray tube. Analysis plays the dominant role specifying the sizes to meet strength, fatigue, flutter, and creep requirements. Detail design determines joining techniques, fabrication methods, cost considerations, etc. Basic concepts have been determined in consultation with many specialists. Who is the designer ?

The ultimate responsibility for the design rests with the project engineer but design considerations have to be taken into account by all members of the engineering team. Every engineer must have a basic awareness of design problems and the foundation must be laid in engineering education. Unfortunately, as shown by the Design Committee of AIAA in Ref. 3, this is not the case.

From this viewpoint the word "designer" implies an attitude which goes beyond a job designation. This attitude is directed toward seeing a problem in its overall context -- never being resigned to act as a small cog in a big machine but always feeling responsible as an integral part of a greater design. The analyst is part designer as well as the designer is part analyst.

*   *   *

It would be unrealistic to expect the designer to master all details in connection with a design. Nor is there any need for it because this is the specialists' task. What the designer needs is a methodical approach to the design process and a clear understanding of the diverse aspects of design so that he can communicate with specialists when necessary and arrive at a balanced judgment. The process of arriving at a balanced judgment is the essence of design and, therefore, a first goal of design education.

There is an additional consideration which is bound to have a most significant influence on the position of the designer. Just as the analyst and the system engineer have delegated much of their routine work to the computer, the designer is in the process of being relieved of much drudgery by computer graphics. This frees the designer's mind for his more challenging tasks, including particularly the creative aspects of design. As the specialists provide him with proper computer programs in design and analysis, he can roam freely over a wide range of alternate possibilities with the most sophisticated tools at his disposal. This will easily exceed the boldest dreams of only a few years ago. Yet clearly visible as the main stumbling block is the computer's GIGO characteristic: garbage in, garbage out. Unless the designer is thoroughly familiar with assumptions and implications of the computer programs and unless he is equally familiar with real-life complexities which are not included in the programs, even the most advanced techniques amount to nothing more than a dangerous and treacherous toy. The designer must understand the sophisticated tools available to him. Whoever may manipulate these tools, the designer must be familiar with their basic principles and must recognize the inherent potential as well as the inherent limitations. This will become the hallmark of good design and must be a second goal of design education.

A final consideration should be mentioned explicitly although it is implicit in the preceding remarks. In a world of scientific specialization it can happen easily that a specialist may be oriented toward theoretical rather than practical aspects and that he is not fully aware of real-life implications. This can result in "paper specialists", particularly in newly developing fields like the "ilities" or system engineering, who have never been involved in design work. The designer must recognize such shortcomings and take remedial action. Such a sense for real-life complexities provides the criterion for a practical design and must be a third goal of design education.

We may summarize the preceding considerations as follows:

- The central role of the designer, namely to guide and coordinate the work of all specialists and to make the trade-off decisions, is emerging only slowly.

- For this role the designer must understand the principles

underlying the specialists' work so that he can communicate with specialists without being an expert himself and that he can compromise between conflicting requirements and make decisions judiciously.

- The range of interest for the designer must reach from sophisticated computer methods to rather elementary real-life complexities and must include the management aspects of his work.

- The designer in the fullest sense of the word will combine a mastery of design techniques with the rare gift of a creative spirit.

- Unless the designer meets the main requirements of such a comprehensive concept, he will find himself confined in a defensive and insignificant position between scientific analysts who provide depth of perception in various fields and the system engineer who provides width of perspective on a somewhat abstract level. Such a subordinate position for the designer would be much to the detriment of engineering.

- A basic need in engineering education consists of instilling an awareness of the design process in the engineering student. There are many roads to design -- frequently beginning with analysis or specialization.

After these basic considerations the questions raised in the second paragraph of this section G.1 can be answered without much difficulty. New methods in analysis, computerization, and system engineering are not superseding the designer. On the contrary, they must become his tools. He has to master them in order to reassert himself in the central position which he lost during the last two decades. The designer is emerging in what seems to be a new role although it amounts basically to not much more than an application of a new set of tools plus an understanding of fundamental concepts and methodology. Whichever way one looks at it, it is a new situation of great significance and it must be understood clearly.

The demands upon a good designer are extraordinarily high and will never be met by many. But every engineer can do his best to develop a design attitude within his own field. This may lead toward an answer to the question: who is the designer ? In a complex design this can frequently be the sum of analysts and specialists acting as an integrated team.

The increase in complexities resulted in more advanced methods of analysis and more emphasis on team work. What used to take place in the mind of one good designer as an intuitive and subjective process has developed into a systematic design process. This design process will be the subject of the following discussions. It indicates an expanded role for design which goes far beyond the traditional concept of designing at the drawing board.

G.2 Outline of the Design Process

To understand the broad responsibilities and the intellectual challenge of design, we may develop in greater detail the definition of Appendix A.1. Design is an activity which

- begins with the conception of an idea, articulation of the need, selection of criteria, determination of constraints, establishment of a value system, as well as impact analysis, problem definition, and visualization of alternative solutions -- the conceptual phase;

- continues with full consideration given to the various components and their integration, optimization, and decision-making -- the formative phase;

- and concludes with details and documentation as required to provide for production and to prove performance and reliability -- the final phase.

This indicates three distinct phases in the design process as suggested by Blumrich in Ref. 36. There is, of course, a considerable amount of idealization in such a simplified system and both first and second phase may be included in Advanced Design. Nevertheless, the following brief discussion will show that different aspects are typical for each of the three phases.

We should look at the first phase of design as being concerned with basic concepts, characterized by a unique interplay of intuition and experience with due regard for the constraints imposed by analysis and synthesis. This represents a process, simultaneously unbridled and yet deliberate, where the human element dominates before specialized analytical methods can take their rightful place. At the same time, the designer must perform a needs analysis and an impact analysis, define the problem, and establish design criteria concerning objectives, resources, value system, and environment. He must feel fully responsible for all the consequences of his decision. He has to anticipate with foresight the type of questions which can easily be asked from hindsight, like "why was it done just this way ? " or "why was that not considered in advance ? " He particularly has to anticipate potential difficulties which may develop in the second phase. Thus the foundation of a design is laid under conditions where the individuality of the designer can unfold and blossom, where creative and analytical capabilities have to be correlated, and where new ideas and assumptions can develop but have to be checked and rechecked.

The second phase of design is of a different nature. It consists of determining the basic details of the components, analyzing them, integrating all aspects in search of an optimal solution, and making decisions consistent with the needs and values defined before. This demands a controlling role for the combination of analysis and synthesis. Scientific specialization and laboratory

testing may play an important part. Yet the most typical aspect is frequently concerned with coordination between specialists of different fields, compromises between contradictory requirements, anticipation of difficulties in manufacturing and processing, evaluation of uncertainties and risks, thoughts about compatibility and optimization, requirements of maintenance and operation, and many other considerations which have to be balanced against one another before a decision is made. Each decision must be tested by examining its effects on other components or sub-systems. Close contact has to be maintained with the user. Inherent complexities and numerous iterations of feedback loops make it essential to find a methodical approach. Thus the development of a design takes place under conditions where engineering methodology plays a dominant role.

The third phase of design is concerned with documentation. Production must be based on unequivocal information, expressed in form of drawings, specifications, or computer tapes. Airworthiness must be documented by detail analysis. All the ideas and concepts developed previously must be followed up thoroughly and translated into numerical values regarding reliability and practical consequences. Thus the final steps of design require full attention to details, much liason with manufacturing, inspection, and customer acceptance, and a clear recording system.

All three phases have in common that as a prerequisite they are based on scientific understanding, analytical capabilities, and engineering skill. Beyond this common base, however, distinctly different qualities are needed for each one. In the first phase the emphasis is on creativeness and imagination, in the second phase on much well-substantiated analytical judgment with a sense for interrelations, and in the third phase on a thorough consideration of final details.

A basic approach to design problems can be characterized by these three phases. However, it should be understood that this is not a rigorous system, that considerable overlap exists among the phases, and that there is no need for a clear delimitation. The purpose is to emphasize that a design is built on quicksand unless full attention is given to the conceptual phase and that a design is imcomplete unless it is properly documented.

The second phase with its emphasis on methodical decision-making forms the core of the design process. Decisions, however, have to be made in other places, too. Wherever this may be, the same methodology is applicable and the present state of the art will be summarized in the following two sections.

G.3 Importance of Decision-Making

Decision making is a most fundamental part of design. Some people make decisions calmly and methodically, others postpone and try to avoid decisions as much as possible. Professionals who are known to make decisions, e.g. executives, physicians, pilots, stockbrokers, may easily explain how they balance in

their minds a great many considerations against each other. This confidence has been deflated sadly by psychological tests. It appears that the unaided human mind can handle hardly more than two or three parameters. Random considerations become dominant when we exceed such limitations and we tend to be satisfied with establishing minima and finding a feasible rather than an optimal solution.

The clear conclusion is that the designer can rely on decisions which he makes in his mind only in relatively simple situations. More complex design problems require a methodical approach. A typical present-day design problem may involve a team of specialists and can easily reach into a region where an optimal solution may exceed the skill of the mathematicians or the capacity of the computers. This is the basic situation which we have to face in design decision-making.

A methodical approach to decision-making has been developed -- much of it outside the engineering field. The terms operations analysis, operations research, system analysis, and system engineering cover a wide range of interest which is closely connected with the process of decision-making. These terms are more familiar to the manager than to the designer. However, if the designer wants to be the principal planner, developer, and decision-maker in engineering, he has to think of himself as the manager of his design. So we should begin with some basic considerations which have to be incorporated into design.

Various ill-defined terms are used in this field and no generally recognized definitions exist. Operations research came into being in the late 1930s and early 1940s as it became evident that new scientific devices remained meaningless unless they were operated in a functional way. Radar, for instance, had to be operated in a certain pattern to cover the whole field of search. Other applications of operations research during World War II were found in connection with convoy routing, stockpiling military supplies, etc. Logical thinking, common sense, arithmetic, and probability served as basic analytical tools.

Then, as time went on and more complex problems were pursued, new methods had to be developed and mathematical sophistication began to flourish. The final step consisted of realizing that it is not enough to analyze a given system but that an optimal system has to be developed, considering the total life cycle and the decision process. This is the domain of system engineering.

Such a rather simplistic sketch may serve to establish a general perspective in a field which is at a very dynamic stage at present. We should realize, however, that the general concept "system engineering" is nothing different from engineering. The term is a tautology where the word "system" is redundant. No engineering is worthy of its name unless it considers the whole system.

In a narrower sense, the system engineer should be the specialist

in refined methods of system engineering just as the production engineer is the specialist in detailed methods of manufacturing. In a broader sense, the designer should consider himself to be the system engineer of his design. The concept of system engineering arose only as systems became so complex that it was difficult to visualize them. It became a special responsibility to integrate and synthesize all component parts -- just another consequence of the fragmentation of modern life. Only recently has the significance of synthesis in engineering been rediscovered and emphasized but it should behoove us well to realize that in all likelihood the medieval builder of a cathedral intuitively knew more about synthesis than the present-day system engineer with all the analytical tools at his disposal.

Now let us turn back to the subject of decision-making. There is a very gradual transition from a simple decision-making situation which can be decided quickly in the mind, over a more complicated situation which one better figures out on paper, to a complex situation which requires quite sophisticated methods. Nothing could be more embarrassing to the designer than unwittingly violating some basic principles of decision-making which are familiar to any modern manager. These principles will be considered in the following section.

G.4 Methods in Decision-Making

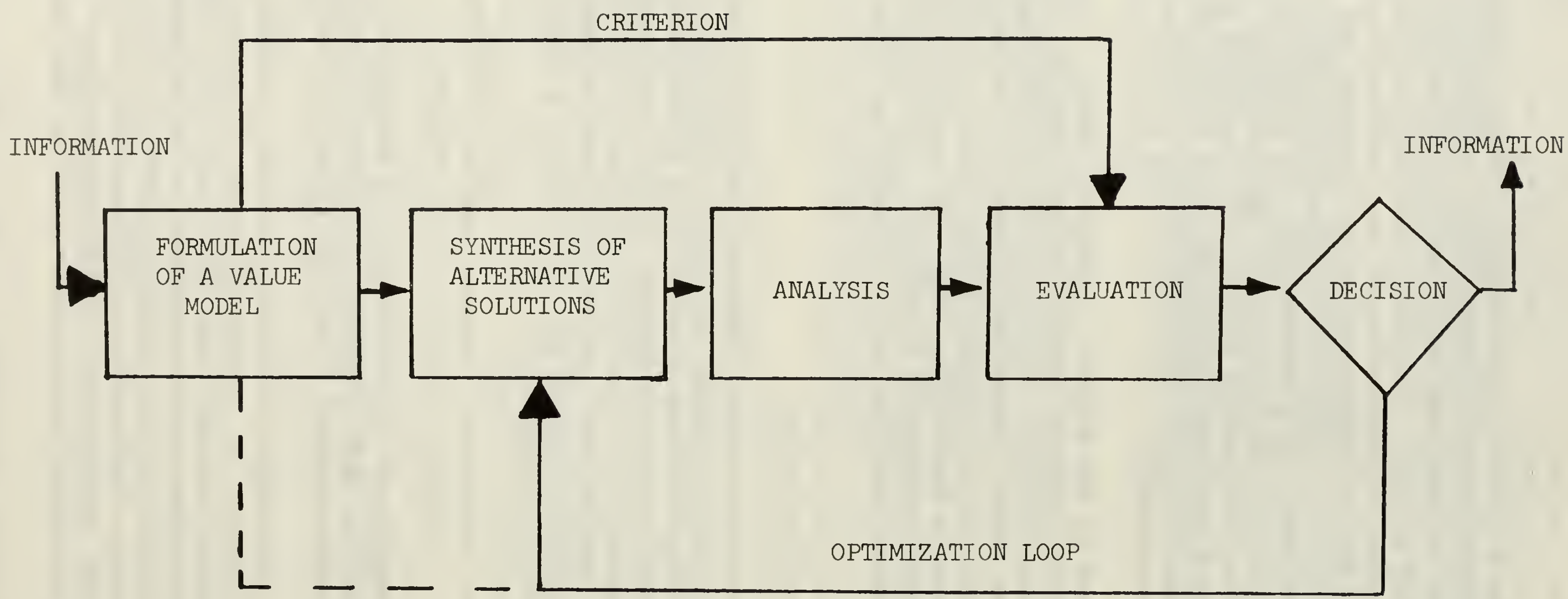
Having recognized the importance of decision-making in design, it becomes essential for the designer to develop a fundamental understanding for the lines of thinking and for the methods which have evolved in the field of decision-making. Such a fundamental understanding is considerably less than full familiarity with refinements, complexities, and implications. Yet it must serve the designer to account clearly for his decisions and to recognize a problem which should be handled by specialists.

The following brief remarks will outline some well-established subjects which are of special interest to the designer:

a. A solid background in probability and statistics is necessary to balance the deterministic outlook of the analyst with the probabilistic outlook which is so significant for the designer.

b. Probabilities express a calculable risk, either objectively based on statistics or subjectively based on informed estimates. Many decisions, however, have to be made under uncertainty. This implies a dependence on the decision maker's preference for possible consequences and on his judgment concerning the chances of these consequences. Preferences and judgment are not arbitrary but based on careful consideration of available evidence. These implications of uncertainty are characteristic for many design decision.

c. A value system is essential to identify design criteria, e.g. objectives, resources, time schedule, costs. Relative



A MODEL OF THE DECISION PROCESS (FROM REF. 39)

FIGURE G-1

importance can be expressed in weighted relationships but, in general, criteria will have several dimensions, e.g. speed in m/h, range in miles, weight in pounds, schedule in calendar days, sonic boom overpressure in $\#/in^2$, or passenger comfort as good or bad. Optimization can take place only with respect to a single criterion function. This has to be found in form of a measure of utility where non-linear relationships have to be taken into account. They may depend on local sensitivities, thresholds, or personal preferences and can be expressed as utility functions.

d. Judgment in decision-making is provided in form of subjectively estimated probabilities. This judgment is based on available information, and methods exist to revise probability estimates as new information is provided.

In the field of structural design a peculiar practical problem exists regarding available information. Test data on materials characterisitics are produced in many places but become meaningful only when correlated with other data and evaluated with respect to clearly specified test conditions. The enormous quantity of data being developed makes it imperative to have data information systems assuring that available data become accessible to the engineering community.

e. Optimization is expressed by feedback loops throughout the decision-making process. A comparison of output with input serves as a guide for modifying previously chosen parameters in search of an optimal solution. Search techniques establish patterns for the most effective modification of parameters. This is a specialized field still in full development where it is even difficult to keep up with the large and ever-increasing amount of literature (Ref. 37 and 38).

f. Based on the preceding subjects, a methodology of decision-making consists of an iterative process with many feedback loops where an input of criteria is transformed into an output indicating the corresponding utility. The fundamental elements of the model are input information (criteria, constraints, value system, alternative solutions, and functional relationships), analysis, synthesis, evaluation, optimization, decision-making and output information. These elements are shown in Fig. G.1 which is reproduced from Lifson and Kline, Ref. 39. Throughout this process, basic considerations are concerned with human judgment represented by subjectively estimated probabilities, with preferences in case of uncertainties, and with utilities as the expression of a value system.

g. The methodology of decision-making shown as item f has been developed for the typical design situation where the parameters can be varied by the designer. Under fixed conditions of decision-making, decision analysis provides an approach using a diagram in the form of a decision tree. Starting from an origin, there are so many branches at any point of the decision tree as the number of alternatives which indicate acts and subsequent events. The original action is under the control of the decision maker.

Subsequent events are partially beyond his control but he assigns values of probability. Every path through the decision tree corresponds to a possible sequence of events, each with its own consequence. There are chance branches and choice branches and a clear logic system with probabilities is shown by Raiffa in Ref. 40. Simple manual computations or a computer may be used.

h. The most fundamental aspect of decision-making is the need to establish a logical sequence and full visibility and traceability for all steps which are taken. There are always uncertainties in design. They must be indicated clearly and presented in a form which encourages discussion. The designer has to face uncertainties honestly, live with them if necessary, and clarify them as soon as possible.

G.5 Real-life Complexities

The preceding considerations about methodology in decision-making are concerned with those aspects of design where full use can be made of the highly sophisticated software which has been developed recently. Now let us turn to some special aspects of the more traditional sides of design.

Under real-life complexities we may collect those problems which, in spite of all the best efforts, have not been anticipated in early design. They develop only after design, test, and production and posthumously they can often be traced to hidden parameters, long-range consequences, uncertainties, or quality control. The designer has to accept basic responsibility because he ought to foresee special circumstances which may legitimately occur. Even if a fault can be traced to the erroneous advice of a specialist, it is the designer's design which suffers.

The field of structural design offers many typical examples for real-life complexities. They happened during the last decade particularly in the fields of fatigue, stress corrosion, and fracture mechanics. Usually the difficulties had their origin in some special combination of circumstances between load spectrum, material properties, stress concentration, design stress level, environmental conditions, fabrication, processing, or maintenance. The specialists had acted in accordance with available knowledge and had good reasons for their decisions but a combination of circumstances caused a new and adverse situation and the overall results were calamitous.

Typical failures were not caused by incompetence in structural design. An amazing amount of knowledge and experience has been accumulated among responsible engineers in all major aircraft companies. The basic difficulty consists of the multitude of potentially critical conditions and the laboriousness of investigating all aspects as the state of the art is pushed forward another step.

Let us look at some examples. In fracture mechanics, slight

processing variations which do not effect other material characteristics can cause a great reduction in fracture toughness. In stress corrosion, comparatively small residual stresses in a transverse fiber direction can become critical under adverse environmental conditions. The importance of these parameters became obvious only after unexpected faults were found from real-life experience. In both cases much research and development had taken place before the significance of these "hidden" parameters was brought out.

In fatigue, after two decades of intensive research and development, we are still learning lessons about translating theoretical knowledge into practical application. Much was found out about design details only when real-life experience could be used to illustrate long-range consequences.

Consideration of uncertainties is another aspect of real-life complexities. Uncertainties pervade the whole field of design and they have innumerable aspects. One of the less tangible aspects is considered by Wilmotte (Ref. 41) in an excellent discussion of the frequent situation where the purpose of a technical presentation is to "sell" rather than to communicate something. This results in a think-positive syndrome which inevitably tends to obscure uncertainties until they become visible as deficiencies and reach crisis proportions (e.g. Ref. 42). Uncertainties have to be brought into the open, not to overemphasize them but to bring them into proper balance with other information. A clear connection exists here between real-life complexities and the role of uncertainties in the decision-making process.

Quality control is concerned with inspection methods. Ref. 43 shows how important it is for the designer to make sure about inspectability. The failure of a steel pivot fitting is discussed where the presence of an internal flaw remained undetected and where improved methods for nondestructive testing and upgraded inspection standards had to be developed. All these details were in the field of specialists. Yet the overall responsibility for the consequences rests with the designer. Fatigue and stress corrosion alone are estimated to have cost several hundred million dollars in necessary repair of aircraft within a decade. Most of these problems occurred on conventional materials which had been considered well-known. Now we are facing the introduction of more new metals, new composites, and new types of construction. This will result in a precarious situation and much attention will have to be paid to real-life complexities.

The important aspect of such real-life complexities is that, by their very nature, they turn up unsuspectedly in spite of much research and development. Neither fatigue nor stress corrosion were new problems when they descended upon the aircraft industry with great vehemence. Yet the full implications were recognized only too late because previous tests and considerations had not completely taken into account real-life conditions.

There is no absolute safeguard against the occurrence of such

surprises. Their number, however, can be reduced significantly by conscientious efforts in many fields. A systematic decision-making process and computer programs will provide part of the answer. Another large part will have to be provided under the heading of experience.

Experience consists of the practical wisdom gained from evaluating the past and, hopefully, one learns from previous mistakes. However, real-life complexities as described above comprise the unforeseen pitfalls of the future. The relationship between this type of future problems and past experience is somewhat indirect. The knowledge accumulated in the past is not significant in itself because real-life complexities will always loom up in a new guise. Experience as such, particularly if it is not exceptionally broad, can easily lead to narrow prejudice and it is only the judicious evaluation of experience which becomes valuable.

Understanding based on experience and insight will provide an engineering attitude which is the best preparation against real-life complexities. We will have to come back to this point in Section G.9.

G.6 Team Work and Interactions

Most designs require team work of specialists. They also require integration of component parts. In either case interactions take place, whether on the level of individuals or on the level of materials and processes. They require a kind of coordination which is typical of design and which is not found in analytical disciplines. This kind of coordination can be anticipated more systematically than real-life complexities. It is closely connected with the basic outlook of analyst and designer.

Analytical specialists have frequently overlapped into the designer's field and assumed a dominant role. This has very obvious reasons. For quite some time the emphasis in engineering education has been on analytical methods as an answer to most problems. The consequence has been that many of the most promising engineers became analytical specialists and looked at design from an analytical viewpoint.

Nevertheless, analytical methods are nothing but tools. The best among analytical specialists are quite aware of this and have reached a degree of maturity and accumulated a breadth of experience which represent enormous assets. They have achieved this by growing beyond their field of specialization and recognizing the full meaning of interaction among various disciplines. When specialists have reached this point, they actually have arrived at the designer's viewpoint. Unfortunately, it takes almost a lifetime of experience before the typical analyst is equipped to deal with the full range of design problems.

The specialist often has to be concerned with minute details. Such details are necessary but much harm can be done if they are not put

in proper proportion and interrelated with adjacent fields. In the field of structural design, for instance, no amount of specialization can solve design problems unless the specialist develops a basic understanding for the interaction between design, structural mechanics, materials, processing, manufacturing, and quality control. Specialized technology and complex interrelations go hand in hand. Interdisciplinary communication is essential but it can be meaningful only if there is a common language and a common purpose.

The common purpose is provided by realizing the large number of problems in aircraft design which become critical only due to additional influences beyond the field of specialized concern. A common language among specialists must be based on a willingness to work as a team. Establishing this common language and the corresponding communication may have to surmount considerable difficulties when professional outlooks are quite different. Differences between structures engineer and materials engineer, designer and operations analyst, or engineer and psychologist are typical examples.

Similar to the conclusion about real-life complexities in the last paragraph of Section G.5, a deep-rooted awareness of the need for integration will provide an engineering attitude which is the best preparation for team work and interactions. We will have to come back to this point in Section G.9.

G.7 Creativity in Design

The creative aspects of aircraft design were easily visible in the pioneering days of aviation. New types of aircraft and the companies producing them were identified with a creative individual who was primarily an inventive engineer but often developed additional organizational capabilities which laid the foundation of a great enterprise. Some of the leading aircraft companies in the U.S. as well as in England, Germany, France, Russia, and other countries still bear the names of these men.

Such creative genius, no matter how intangible a quality it is, stands out and is recognized by those who see it in action. To define it is much harder. What traits distinguish a creative individual ? Is the creative impulse nurtured or hindered by education ?

Creativity, unfortunately, has become a badly overworked word in the world of advertising slogans. The more modest engineer prefers to think of it in terms of inventiveness or innovation. The domain of creativity provides much challenge to psychologists who are trying to work their way toward the core of the problem. They are concerned with the element of effective surprise, with the motivation for the creative act which may be ego-oriented or task-oriented, with the role of heuristics in problem-solving, with the deadening influence of conformity as an indication of lost self-reliance, with the emergence of new ideas from brainstorming sessions, and many others. Early and comprehensive answers can

hardly be expected.

In the field of engineering, an important step was taken with the National Conference on Creative Engineering Education at Woods Hole, Massachussetts in September 1965 (Ref. 26). The principal aims were to explore the opportunities for teaching the techniques of invention and innovation in the engineering schools and to discuss the development and support of creative engineering education as effective means for meeting the needs of society.

The participants in the conference were distinguished educators, executives, inventors, innovators, and entrepreneurs. It was a rare gathering of many creative individuals for a common purpose. The result of the many presentations and discussions was a good number of clear recommendations which can be summarized as six principal themes:

- Invention and innovation are the essence of creative engineering for technological change and social and economic progress.

- The art of creative engineering has been orphaned in engineering schools, both at the undergraduate and graduate level.

- The creative requisites of invention and innovation, including entrepreneurship, can be developed by involving students in projects. An environment evoking and encouraging corresponding talents can be provided.

- Much has to be learned about the processes of technological change to understand their nature, consequences, and determinants from a comprehensive and interdisciplinary viewpoint.

- The climate for creative engineering education has to be improved by changes in the system of evaluating students and faculty.

- Greater cooperation and better communication are needed among universities, industry, foundations, professional associations, and government -- resulting not only in exhortation but in tangible support.

These six themes are just as important today as they were in 1965. It would be euphemistic to say that much progress has been made. One aspect, however, has been recognized to some extent: the need to expose the engineering student to a design experience during his freshman year or the first part of the sophomore year. Several universities have incorporated such a course in their program.

From the viewpoint of creativeness this is particularly meaningful if one considers that creative impulses are at their peak in a two- or three-year old child, are badly diminished by the time the child is in elementary school and taper off farther

throughout high school and university. Creativity needs encouragement. In our conventional educational system it almost seems a small miracle to have any sense of it left by the time a doctorate is obtained.

Two additional aspects are usually considered for an introductory design course: it should serve to motivate the student toward engineering and to illustrate the difference between design and analysis in addition to giving the student an opportunity for creative work. Various formats have been used for such a course.

Arizona State University introduced a 3-hour freshman course in creative design in the mid-60s (Ref. 44). About 400 students are split into sections of not more than 30, with graduate assistants, mostly doctoral candidates, as instructors. Each student generates a design problem, identifies the physical need, and submits a proposal to organize an engineering company. Students submitting the best proposals become leaders of groups of six students undertaking the development of a proposed system or device. Typical steps are: problem definition, specification of criteria, brainstorming, choice between available alternatives, identification of critical components and consideration of details, progress reports, marketing considerations, working model, if possible, and preparation of a written report plus visual aids and oral presentation.

As a most essential aspect of this course, a large number of experienced practicing engineers have volunteered as consultants when design problems arise and as judges of the competitive projects at the end of the course. Besides, during one of the three weekly one-hour sessions, all students meet jointly to hear an invited speaker relate some of his personal design experience. The exposure to the real world of engineering and the contact with practicing engineers is a good balance to the theoretical courses of the freshman year.

The Thayer School of Engineering at Dartmouth College has a well-established course Introduction to Engineering in the first term of the sophomore year. The objectives are to provide:

- an authentic experience in engineering and an opportunity for creativity;
- practice at inductive reasoning, scientific problem solving and first-order analysis;
- an opportunity to design and test a prototype;
- practice at project planning, organization, and budgetary control;
- practice in the use of information sources and in written and oral communication;
- and an awareness of the non-technical aspects of engineering.

In the fall of 1972 different proposals on solid waste disposal were developed by five groups of six students each. Each group had a faculty advisor and a graduate student advisor and had to make a final presentation of its project before a review board consisting of representatives from industry and faculty. The students gained a thorough overview of engineering in this course to help them decide whether they wanted to become engineers.

Many variations of such introductions to design are possible. More emphasis can be put on do-it-yourself workshops, building prototypes on a budget restricted to a few dollars for material; or on brief "fun" projects like designing, building, and testing the lightest or smallest package to protect a fresh egg in a four-story fall; or, as UCLA did it years ago, starting with a field trip to a mass production plant for making toys and then giving each freshman the assignment to develop an educational toy all the way from feasibility study and conceptualization to optimization, fabrication, and testing of a prototype (Ref. 45).

A different approach to deal with creative abilities of students is practiced in the Design Division of Mechanical Engineering at Stanford University (Ref. 46). Faculty members believe strongly in the possibility of enhancing the creative ability of their students. In solving problems, the creative contributions of individuals and the dynamics of small groups are explored. Conceptualization plays a considerable role and conceptual blocks may be of a perceptual, emotional, cultural, environmental, or intellectual kind. The main emphasis is, of course, on project work of great diversity, usually connected with the building of a working model.

A great many courses are given by the Design Division at Stanford, including a team-taught integrated series of three quarters on a graduate level which consists of project work carried through fabrication and testing. Special emphasis is given to the conceptual and the development processes, information collection and organization, failure mode prediction, legal aspects of design, use of the computer and of mathematical analysis in design, protection of intellectual property, production considerations, interpersonal problems faced by the designer, design aesthetics and man-machine integration.

G.8 Descriptive Geometry, Computer Graphics, Design and Communication

A drawing traditionally has been the language of the engineer and his principal means of communication. Some basic aspects may be considered from the viewpoint of design education.

Descriptive geometry and engineering graphics have lost the basic position they used to hold in engineering education. This is in line with the increasing emphasis on analytical aspects of design. It does not mean at all that engineering drawings have become less important. Yet, in accordance with the general trend toward computerization, drawings are increasingly produced by computers.

Courses in computer graphics have been taught on an early sophomore level as well as on a graduate level (Ref. 47 and 48). A simple computer-driven X-Y plotter is used or a more sophisticated cathode-ray tube display which permits animation and interactive graphics. Fortran, descriptive geometry, and graphics provide the principal tools but programming can become quite time-consuming and prepared programs may have to be used.

There are many fascinating aspects to computer graphics, and applications in industry have developed rapidly since the late 1960s. Interactive computer graphics can guide the designer through the process of analysis and design, and the graphic console provides him with the opportunity to adjust his method of approach or the basic geometry in accordance with partial answers.

Availability of time-sharing computer systems and inexpensive graphics consoles has revolutionized the scope of design. Graphics equipment and man-machine communication can provide an insight which has been completely lost in the sheer bulk of automatic computer output. This insight had existed in manual design methods -- but only on a modest scale due to time limitations. The newly gained insight is something new in the design process.

As pointed out by Au in Ref. 49, complete automation of the design process under complex conditions is at present neither technically nor economically feasible and one must rely on the heuristic approach in search of solutions. This means the use of some selected strategies to stimulate investigation. It implies that engineering education should include activities which require frequent exercises of judgment and creativity and the use of engineering games is suggested.

Coming back to the application of computer graphics, many examples can be given. In the design of frames, beams, and shells the input consists of design configuration and parameters, the output displays shear and moment diagrams, displacements, and stresses. Cross-sections are defined by modifying basic shapes with the light pen and the computer program furnishes section properties and other details at the touch of a button.

For a production drawing, the information stored in the computer is plotted on either an X-Y plotter or on a microfilm plotter. If parts are to be manufactured by numerical control, this can be incorporated in the program. If parts are to appear in the maintenance manual, an isometric view can also be included in the program.

Considerable pioneering work in the field of practical application has been done by Lockheed, and drawings and wiring diagrams are produced routinely by computer graphics. Training techniques for computer graphics designers are described by Noble in Ref. 50. A background in engineering graphics and descriptive geometry is essential. Another important aspect is a capability to visualize.

This leads to a field which is given considerable attention at Stanford and has been developed as a concept of Visual Thinking by

McKim in Ref. 51. There is a close relationship between visual thinking, seeing, idea-sketching, and imagination.

From idea-sketching it is only a small step to communication in form of the spoken or written word. The frequently unsatisfactory level of report-writing has been a subject of unceasing concern and no good solution has been found yet. The proper place to solve the problem, of course, should be in high school.

We may summarize the preceding considerations as follows:

- Man-computer interaction with screen display and light pen has become a fundamental tool of design; it has to be incorporated in all aircraft design curricula.

- Computer graphics with all its implications may be considered to be a specialized field; whether it is included in an aircraft design curriculum will depend on the educational objective of the curriculum.

- The designer who can communicate with the computer should also be capable to communicate effectively with people: orally, in writing, and with quick sketches. This, however, is true for any engineering curriculum.

G.9 Education for Approach and Attitude in Design

Much time has always been required in engineering education to develop in the student not only the methods but also the spirit of scientific analysis and experimental verification. The underlying principles of analysis appear so frequently in so many courses and in so many forms that the student cannot help absorbing them as a fundamental part of his mental equipment.

The same is true for design. The design approach combines creative concepts with methodology. Unfortunately, we do not understand much about the creative aspects. So it must suffice to develop a methodology where the input is hopefully influenced by creative impulses. We build an analytical model, synthesize many analytical iterations, and obtain the design process. The result is of a very different nature than analysis -- inductive instead of deductive thinking. This develops and grows slowly within the student. One should not expect that such a big and important step can be taught successfully in a single course at the end of the curriculum.

The difficulties inherent in a design course were discussed in Appendix F.2. There is a growing awareness that the basic concepts of design and synthesis do not have to be confined to a design course but can be introduced into many courses which have been taught traditionally from a purely analytical viewpoint. The essential aspects of introducing the student to design and synthesis throughout the curriculum may be quoted from Gawain in Ref. 52:

"Synthesis, like analysis, can be taught at various levels from

the most elementary to the most advanced. It is strongly preferable that both sets of skills be developed concurrently. It is an all too common educational fallacy to keep postponing indefinitely the rewarding and educational experiences of creative engineering design in a frantic effort to cover more and more theory. The real educational task should be to integrate design skills progressively with the student's gradually increasing ability in theory and analysis. Moreover, while analysis and synthesis are of course strongly interrelated, it does not necessarily follow that one develops the student's ability in design primarily by drilling him in techniques of analysis. In fact, there is much evidence to suggest that excessive drill in analytical procedures may actually kill design creativity and motivation.

"Much can be accomplished toward teaching design skills by careful selection of the type of problems routinely assigned in the various courses. Thus in an elementary course in structures, a conventional analytical problem might be, for example, to specify the configuration of a truss and the loads acting upon it, and to require the student to determine the loads in the individual members. An appropriate design problem for this stage of the student's development might be for him to design a truss capable of supporting specified loads. Suitable constraints on allowable stress might be specified, and the student could be asked, for example, to minimize the overall weight of the structure. In a course, say, on performance of helicopters and VSTOL aircraft, it would be appropriate to have the student determine and lay out the principal features of a helicopter rotor suitable for producing a specified lift under specified conditions, including appropriate constraints on size, efficiency or power required. In a course on engineering thermodynamics, it is a common exercise to ask students to estimate, say, certain performance characteristics of a jet engine having a prescribed thermodynamic cycle. This problem is easily "turned around". We can ask the student to work out a suitable cycle, and suitable flow areas at principle cross-sections, for a jet engine intended to meet a specified performance target. Certain constraints on maximum cycle temperature, maximum rotor tip speed and so on would naturally be invoked. As the skill and sophistication of the student develop, the problems can become more complex, and the initial specifications more tentative in character, thus throwing more of the creative burden of the problem onto the student himself.

"Naturally, the solution of creative design problems of this kind involves much trial and error on the part of the student, and much painstaking evaluation and guidance from the teacher. These tasks demand considerable effort and time from both student and teacher. However, they are indispensable for building the student's ability to do original creative work. No amount of drill on trivial exercises of the "canned" variety can substitute for the experience of struggling with these more untidy problems that more or less simulate real life. No amount of passive attendance at lectures can develop the active skills and the basic self confidence that are essential for the successful solution of non-trivial problems. Hence, if synthetic problems require time, a rational curriculum

will allot the necessary time for this purpose at the expense, if necessary, of other desirable but less urgent requirements. At the present time, we are falling considerably short in this respect. Except for thesis work, virtually all of our academic offerings, irrespective of their alleged scholastic level, are actually of the spoon-fed variety."

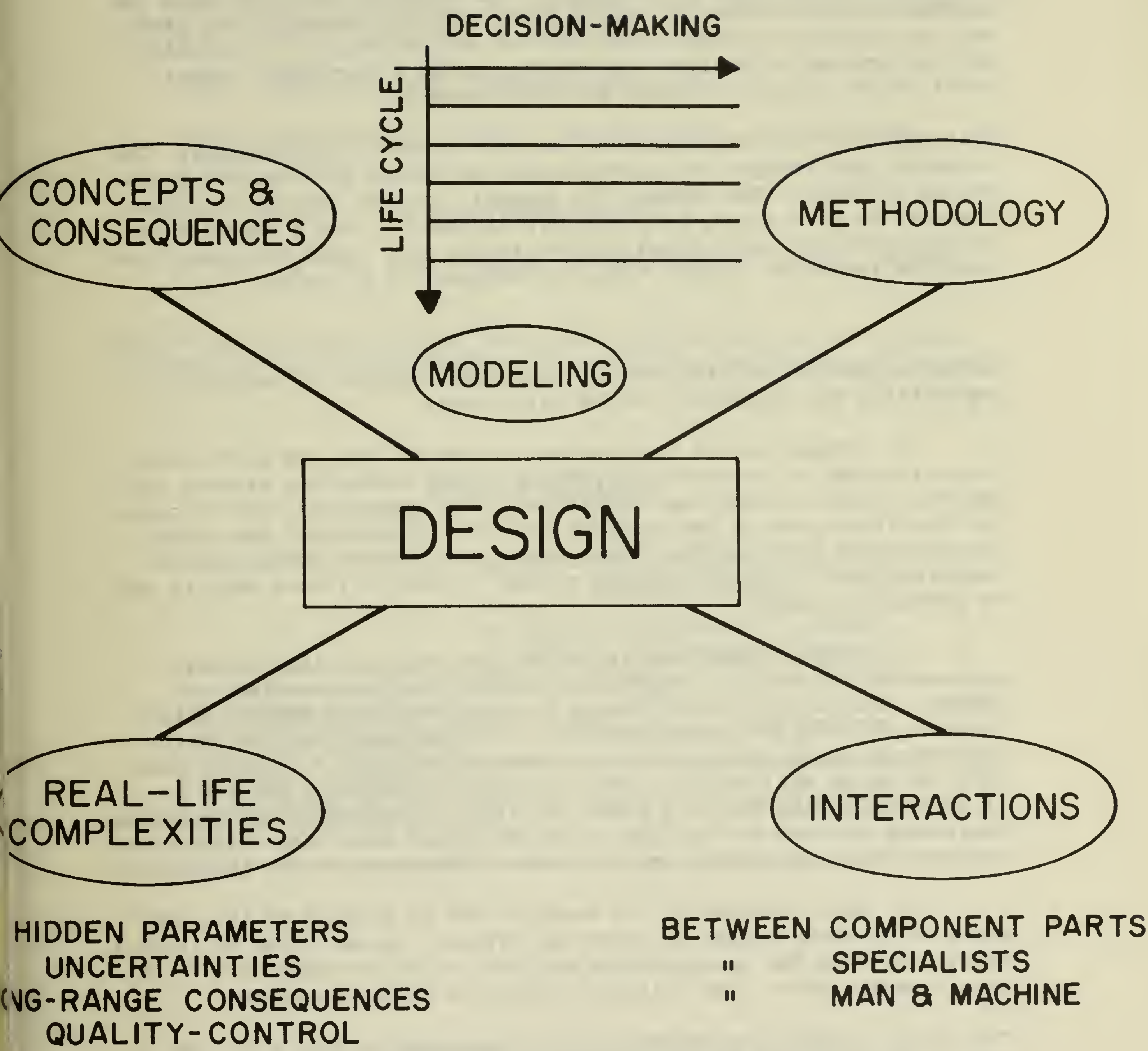
Along a similar line of thinking, it is suggested in Ref. 35 to integrate the individual efforts of such mini-design problems by introducing the same operational requirements for one or more flight vehicles into various aerospace courses. This can make design a part of every aerospace engineering course. It adds a purpose to the specialist courses and also gives the student a feel for numbers and for the importance and significance of key parameters and characteristics.

It would be very helpful to have a collection of typical design problems in various fields. A good beginning was made by Shanley with Ref. 53 for elementary mechanics and strength of materials. This field is particularly suitable as a first introduction into design methodology but corresponding problems should be made available in other fields.

So much about developing an awareness of the design approach throughout the curriculum. Correspondingly, within a well-balanced curriculum the student can develop a design attitude, always being on the lookout for uncertainties, long-range consequences, interactions, and hidden parameters. This falls in the field of experience which the designer has always had to acquire slowly by accumulating it over many years. Experience cannot be learned. What can be learned, however, is a readiness to learn from the experience of others, to recognize the root of the problem, to understand and evaluate contributing factors, and to transfer judiciously the lessons learned from one problem to another. Much valuable work has been done in this field as the Engineering Case approach was developed -- in analogy to the cases in medicine and law which serve as precedents for solving similar but different problems.

Supported by NSF, Stanford University has developed a large library of case studies (Ref. 54). They are based on real-life experiences which are significant as examples of complex engineering problems, with a detailed description of all complexities and the considerations which finally led to the solution. Beyond this systematic collection, aircraft accident investigations offer excellent examples of case studies, alerting the student to the importance of smallest details. The purpose of case studies is to bring the student close to actual conditions as they exist in engineering practice and to develop an attitude of responsibility for every aspect of a design, no matter how subordinate it may appear. Case studies can be used for reading assignments and topics of discussion.

Another application of case studies has been practiced at the



DESIGN CONSIDERATIONS
Fig. G-2

University of California at Berkeley. Instead of doing experimental or theoretical thesis work, a team of two or three graduate engineering students is assigned to a troublesome problem which has been encountered and solved in industry. Engineers who have worked on the problem are interviewed by the students, all aspects which may have had any possible bearing on the problem are thoroughly investigated, and the problem is analyzed and written up in a form which contributes to the future knowledge and understanding.

This approach has been rewarding for both students and industry. The students gain insight and understanding of design problems and engineering practice. The company, in general, and the concerned project engineer in particular, get considerable benefit from a report which usually goes into more depth of the problem than could have been done with the available budget, time, and manpower of a company.

* * *

Design education can also develop some basic aspects of design by emphasizing the continuity of the life cycle:

a. Design has to be perceived as the initial and most consequential stage of a continuous process. This continuity extends over manufacturing, testing, and certification to operational use throughout the life cycle of the designed product. Design must take into consideration anything that might take place farther downstream in the life cycle of an engineering system -- even if future details can be worked out later.

b. These future details may be the responsibility of test engineering, production engineering, maintenance engineering, or others. They still present design problems with many aspects which require planning and decision-making. In each case the same basic three-phase design process as discussed in Section G.2 is applicable; only the scope will differ. The corresponding decision process is in accordance with Fig. G.1 where the input is determined by preceding decisions upstream in the life cycle and output must take into account whatever the consequences may be farther downstream in the life cycle.

c. Most important: The designer has to develop an attitude where he is always aware of cause and effect. He may think of it as a continuity from the conception of an idea to the consequences of the idea's realization. The full life cycle has to be considered.

The various design considerations are summarized in Fig. G.2. The upper part indicates the continuity from concepts to consequences as design is subjected to a methodical approach with modeling and decision-making. The lower part indicates the regions where methodical planning may find its limitations, e.g. interactions between parts or between people or between man and machine, or the wide field of real-life complexities.

* * *

There is still another aspect of design which should be considered

for educational purposes. The decision-making process, which is so typical of design, can take place on various levels of responsibility. For a supersonic transport, for instance, in a simplified form the levels of responsibility may be represented as:

small components, e.g. brackets, ribs, etc.;

large components, e.g. wing, control system, engine installation, etc.;

total product, e.g. supersonic aircraft;

overall system, e.g. economy, ground support, traffic pattern, etc.

The design process with its three basic phases takes place on each of these levels and we may think of the following matrix arrangement:

<u>DESIGN ACTIVITIES</u>

		DESIGN PROCESS		
		CONCEPTUAL PHASE	FORMATIVE PHASE	FINAL PHASE
DESIGN LEVEL	SMALL COMPONENTS			
	LARGE COMPONENTS			
	TOTAL PRODUCT			
	OVERALL SYSTEM			

The rows represent design levels and the columns represent the phases of the design process. The matrix element in the second row and first column, for instance, would contain early estimates of weight, dimensions, cost, alternative solutions, anticipated difficulties, etc. of all major components. Different types of major components, like wing, propulsion, avionics, control system, are lumped together in the same element of the two-dimensional matrix but they can easily be separated in a third dimension.

The matrix illustrates the wide scope of design activities. In the horizontal direction, each of the three design phases indicates

emphasis on a different personal quality of particular significance -- creative planning, methodical decision-making, or meticulous thoroughness for details. In the vertical direction, each of the design levels emphasizes a different level of responsibility. Correspondingly, the third dimension would separate fields of specialization.

Such a matrix can serve to illustrate the variety of conditions under which designers have to work. The individual designer must find his proper place or, better, lay out the path of his career within this framework. He will usually begin with small components and advance to greater responsibility in accordance with talent, experience, educational background, desires, and circumstances. He may move between various design phases or he may find that one of them is most suitable to him. He may become a specialist or avoid specialization. Yet the basic approach to the design process is the same everywhere.

To emphasize this point: the design of a small bracket, for instance, is a purely technological problem. The designer begins with defining the problem and considering alternative solutions; he continues with detail considerations and decisions, always aware of the interaction between function, material, processing, manufacturing, weight, strength, cost, maintenance, etc.; and finally he provides the proper documentation.

The design of a whole transportation system, on the other hand, may easily reach into regions far beyond mere technology and demand a much wider perspective. Yet the designer who bears overall responsibility has to use the same kind of approach as for the design of a small bracket -- only the scale has become much larger and more complex. For this reason, the basic aspects of the design process are so fundamentally important.

G.10 Summary of the Design Process

We saw that a methodical approach and an attitude which is developed by experience signify two different aspects of the design process. When they are understood they will coalesce and merge into a unity. How can this unity and entirety of the design process be taught ?

This is an open-ended problem. An analysis of its basic aspects has been attempted on the preceding pages but a solution depends on available resources, talent, and time and will be different in each individual case.

It should be realized that much still remains to be done in the field of new concepts. Some of the methods for decision-making under uncertainty and for optimization are still at a comparatively early stage of development. Our understanding of creativity is still at a stage of infancy. Much of the methodology which has been advanced in the field of system engineering remains on an abstract level and has not yet been applied to practical engineering work. There is ample room for evolutionary progress by cooperation between engineers and non-engineers in these border regions of

engineering.

Throughout these considerations it has been emphasized that we are passing through a period of change with respect to design. As always in such cases, it is necessary to weigh and consider new concepts, reflect upon their implications, and understand their meaning before they are introduced.

The fundamental educational aspects of the design process as developed in this appendix are summarized as basic needs in the conclusions of Section 6.1.

* * *

There is an additional aspect of a fundamental kind. Throughout these considerations it was emphasized that the designer has to combine analysis with synthesis and has to develop an overall viewpoint for methodical decision-making. However, overall viewpoint and decision-making are principal characteristics of management. This indicates that design can be considered as a basic preparation for engineering management.

The young engineer in industry recognizes quickly that there are two roads leading upward: specialization or management. Specialization means penetration in depth but implies dependence on the vacilations of the market. Management means expansion in breadth but frequently implies fierce competition with survival of the fittest.

Many of the most promising young engineers are attracted by the road to management. Under present conditions, having been educated toward analysis and specialization, they supplement their technical specialization with additional courses in management as soon as possible. Frequently this means that young engineers, before they have developed their engineering capabilities, concentrate their efforts toward cost accounting, marketing, and financial management. Perhaps they will also take additional courses to overcome a parochial and deterministic viewpoint. They move into administrative positions, are over-occupied with doing paper work and attending meetings, and are carried away from engineering work before they have come to grips with challenging engineering problems.

This is an undesirable and wasteful trend. A good design education must give the engineer a well-founded assurance that he is basically prepared to assume broader responsibilities. With this self-assurance he can concentrate on his engineering tasks and prove himself in his own field. This provides for a natural growth and should take precedence over administrative duties. Studies in management and business administration can wait until later.

The designer who has to coordinate the problems of specialists can be considered to act as an engineering manager. He starts on a small scale with a potential for growth to positions of great responsibility.

Implicit in these considerations is the difference between two basic viewpoints: either the engineer can be a specialist who has to solve problems which are assigned to him by others, or the engineer can be a planner and decision-maker who is prepared to take a responsible part in the highest councils.

Traditional engineering education has prepared the engineer to become a technical specialist while management takes place in a different sphere. New concepts of design education tend to bridge the gulf which presently exists between engineers and managers.

We should also emphasisize another aspect of the design process which appeared only briefly in the preceding discussions. Decisions must be based on a clear value system which comprises both technical and non-technical factors. The technical factors are obviously of an engineering nature. The non-technical factors enter wherever the technical product interacts with society or individual. This is the domain of humanities and social sciences and will have to be considered in connection with professionalism in Appendix I.

APPENDIX H

UNIVERSITIES AND INDUSTRY

It remains amazing that the recent emphasis on science and research in aerospace, which was outlined in Appendix C.1, took place at the expense of broader engineering aspects as much as it did. There were, at the same time when aerospace faculties directed their attention toward scientific specialization, men in the aerospace industry who had conceived clearly a new and broader role for which engineers had to be prepared. Ramo in 1962 called it a new pervasiveness of engineering (Ref. 2). He outlined the need for engineers to cover a new, enlarged intellectual pursuit -- very much along the lines of assuming greater overall responsibilities. Others called attention to the increasing complexities of engineering. Bollay, as a visiting professor from industry, established interdisciplinary courses in the mid-1960s as described in Appendix B.1.6. He coordinated various fields of specialization and brought recent industrial experience into academic projects -- somewhat along the lines called real-life complexities in Appendix B.2.

Yet these efforts, initiated by men from industry, did not find the kind of resonance throughout universities which they deserved. Interdisciplinary courses require much preparation and organization and are based on a number of faculty members who are willing to commit themselves full-heartedly and who have grown beyond their fields of specialization. To envision the wide perspectives of a new pervasiveness of engineering, as Ramo expressed it, also requires people who have grown beyond engineering specializations. Aerospace faculties, however, have gone the opposite way. As discussed in Appendix C.1, they became overwhelmingly absorbed in scientific specialization. This was done decidedly and emphatically and a discrepancy developed between science-oriented aerospace curricula at universities and practical needs in industry which require orientation toward design.

This discrepancy between available output from universities and required input in industry has been stated clearly for many years. Already in 1968 McCarthy and Ginn proposed remedial action (Ref. 55). In 1971 the Design Committee of the AIAA sounded the alarm that only less than half of the curricula of aerospace-engineering schools include design in some form and that "many of the graduates do not seem to be aware of or particularly interested in the design function" (Ref. 3). In 1973 during the panel discussion on "Design for Survival" at the Annual AIAA Aerospace Sciences Meeting, Professor Hazen of Princeton stated: "the tragedy of our engineering schools is that in their drive to produce applied scientists, they emphasized the science at the expense of the application" (Ref. 56).

It seems that the most fundamental explanation for the neglect of design during the ascendancy of analysis can be found on a very human level:

- science-oriented faculty, with a background in research rather than in engineering, did not appreciate the role of design;

- faculty identified with engineering and design developed somewhat of an inferiority complex in view of glamorous scientific break-throughs which overshadowed the role of design engineering.

As a consequence, design was squeezed out of many curricula and surrendered by default. An interpretation of engineering as applied science was meekly accepted and design was at the bottom of the totem pole. As shown in Appendix B, a noticeable reaction to this situation has developed in general engineering education. Yet the great majority of aeronautics curricula has kept surprisingly aloof from any commitment to design.

More and more frequently the complaint has been voiced by industry that the universities have done a very respectable job in preparing researchers and analysts for specialized tasks but that universities are not preparing engineers to recognize and solve the kind of complex engineering problems which are typical for industry. Both types of graduates are needed and the proper balance has to be found.

For a general background it is of interest that in the aerospace industry less than 20% of the number of graduate engineers holds aerospace-oriented degrees (Ref. 57). This heavy reliance of the aerospace industry on non-aerospace engineers is quite significant. It indicates that specialization in the field of aerospace is needed only for a small part of the available engineering positions. If additional statistical data were available, they would probably indicate that the overwhelming majority of B.S. graduates go into design-oriented positions and that graduates with advanced degrees will be distributed roughly half and half between research-oriented and design-oriented careers.

Yet for over two decades undergraduate programs increasingly prepared the engineering student for a subsequent graduate program which has been devoted almost exclusively to research. Problems of engineering practice played a decreasing role. As a consequence, or perhaps more properly as the basic cause of this development, typical engineering faculties have been much more research-oriented than practice-oriented.

Expanding design concepts are, of course, the result of a practice-oriented outlook which has to be brought in balance with the research-oriented attitude of typical engineering faculties. Both orientations complement each other and a continued dialogue will have to provide for gradual shifts of emphasis to find a proper solution. This dialogue should be encouraged and even provoked as much as possible rather than avoided as it is done frequently.

The main problem must be recognized clearly: Present engineering faculties have to a large extent drifted away from engineering practice. This is a very unhealthy situation. As expressed by

Gawain in Ref. 52:

"The teacher himself should be an able practitioner of the art he is endeavoring to impart. However, the present rules of academic gamesmanship are such that they tend to discourage the able designer from joining the teaching profession. For one thing, the skillful and creative designer is highly paid and highly esteemed in industry. For another, the design-oriented individual is often not interested in the "publish or perish" game which dominates academic life. Academic policies on pay, promotion and tenure stress research ability, as evidenced by publications, as the primary criterion and royal road to success. Hence our faculties consist, by and large, of able and prolific research scientists. Comparatively few of them have any very strong commitment toward engineering design and synthesis. Research scientists are just naturally more inclined to be primarily analytical in orientation."

This does not mean that "publish or perish" should be replaced by "practice of perish." Rigid rules can do much harm. Yet a typical academic career pattern should include meaningful industrial practice. In addition, it is desirable particularly for younger faculty members to intersperse academic teaching with occasional summer work or a sabbatical year in industry. Most of the generous provisions which the aerospace industry had offered in this field were cut back in recent years due to external circumstances but it may be hoped that they will be reinstated. For several years the Ford Foundation has had a program under the auspices of the American Society for Engineering Education to afford engineering teachers resident experience in industry.

Recognition of the importance of design in engineering education means also the need to recognize that the gifted teacher in the field of design will usually not have a doctorate nor a long list of scientific publication to his credit. His professional standing must be judged by a different scale and corresponding administrative provisions have to be made.

Some universities have been able to attract outstanding practicing engineers on a temporary basis. As visiting professors they would be on leave from their company for a limited time or as adjunct professors they would continue work with their company but be available at the university for certain days or half-days each week.

There are other possibilities for close contact between universities and industry. Examples in connection with design courses were mentioned in Appendix G.7 with practicing engineers acting as consultants or judges. Universities with co-op programs sometimes take good advantage of contacts established by their students. A few efforts have been made to use work being done by a young engineer for his company as a thesis project. Undoubtedly much more can be done along similar lines. Consulting work done by faculty members for industry is, of course, an important aspect.

A good deal of long-range planning has to be done by universities

with respect to engineering. It will require a clear recognition of the basic differences in purpose between educating a scientist, an engineer, and an engineering technologist. At present, most universities provide principally for the education of the research engineer with B.S., M.S., and Ph.D. but engineering programs with Master of Engineering and Doctor of Engineering degrees are beginning to receive more attention. The Engineering Master Plan Study for the University of California (Ref. 32) was mentioned in Appendix B.1.7. There is a good possibility that the D. Eng. will require some industrial practice -- which would provide another field for cooperation between universities and industry.

The respective roles of engineers and engineering technologists must be understood clearly by engineering faculties and the increasing interest in engineering technology will be discussed briefly in Appendix N.3. It poses a definite challenge to engineering curricula at universities.

On the part of industry, much willingness is found to cooperate with universities and it appears to be up to faculty members to make full use of this. At the same time a certain decorum has to be observed to avoid making a nuisance of oneself because time and manpower are at a premium in industry.

One field where the aerospace industry could do a great service to itself as well as to universities concerns the clarification of educational requirements in future engineers. This is a question of making a systematic survey. The difficulties of obtaining statistics in the field of engineering employment will be discussed in Appendix N.2 and a new procedure may be required.

As a first approach, Ref. 58 may be used which is based on evaluating a large sample out of 438,000 identifiable professional members in engineering societies in 1967. However, only 12% of them were in aerospace. This large cross-section of the total engineering profession indicates 29% in management, 15% in research and development, 15% in design, 12% in consulting and construction, 10% in production, maintenance, quality control, testing, etc., 6% in sales, and 12% for others. Some qualifications are necessary with respect to the composition of the membership in engineering societies. Nevertheless, these figures imply how one-sided an overemphasis on research aspects in engineering education can be because a majority of the engineers who are not employed in research can be expected to profit more from a design-oriented than from a research-oriented outlook.

Usually such surveys are made by mailing questionnaires which are partly answered in a haphazard way, partly filed in a waste basket, and are frequently of limited value. More meaningful results may be obtained by having a team of graduate students (e.g. business administration and aerospace engineering) conduct systematic interviews as a basis for a thesis project to identify educational requirements.

A project of a somewhat similar nature was conducted recently for one of the major aerospace companies. A team of three candidates for the Master of Business Administration studied the company's policy regarding Recruiting, Placement, and Retention of College Graduates. The report contained about two dozen recommendations with means of implementation and corresponding discussion and was accompanied by an oral presentation to staff members. The company felt that the report was comprehensive and provocative and a company review committee was established for a careful internal analysis of the report as a basis for recommending and implementing any changes or new departures that might seem indicated.

Such examples show how much can be done in the field of interaction between universities and industry. Industry can reap a harvest in fields which may otherwise remain neglected, faculty members can find meaningful thesis subjects, and students will gain insight and understanding regarding real-life conditions.

This points toward a basic question which faces aerospace faculties: Can we find the proper mix between scientific research and engineering design ? The answer to this question should be found within the framework of some given facts. First of all, the inertia inherent in any academic faculty, a condition which is both good and bad, must be reckoned with as a circumstance which requires a systematic and reasonable approach. Secondly, the basic recognition which has been accorded to the need for scientific research must not be jeopardized. Thirdly, a newly developing awareness of the relationship between engineering developments and human needs must be recognized. Finally, the anwer will not be the same for all institutions because it will depend on educational objective and available talent.

General developments can be expected to be toward the expanding concepts of Appendix G and the revised ECPD criteria of Appendix B.1.7. A particularly important role will fall to continuing education which will be discussed in Appendix J.

* * *

Considerations about universities and industry indicate some special characteristics of aircraft design which set it apart within the general field of design. Both aerospace faculties and aerospace industry belong to a clearly identifiable community where the aircraft designation emphasizes the aspect of routine operation -- as opposed to the unique effort in space where man and machine are prepared meticulously for a single mission.

Aircraft design has to take into account a long life cycle with innumerable uncertainties and interactions on a routine basis. This aspect, combined with high demands for performance along the frontiers of available knowledge and with harsh penalties for errors, represents unusually severe requirements and calls for special efforts.

The kind of effort exerted by industry is shown in the Proceedings of the Monterey Symposium on Design Problems in Aircraft Structures (Ref. 92). They give a good survey of recent experience with specific design problems and with structural design considerations. This may serve as an illustration for the complexity of interactions and for the magnitude and intensity of the effort required on the purely technical level in aircraft design.

Considering the complexity of the situation and the close interaction between theoretical developments and practical application, the need for full coordination between academe and industry is obvious. Aircraft design faces the task of utilizing newly developed synthetic materials within a spectrum reaching from VTOL to hypersonic vehicles. The educational needs are urgent. This is the reason for giving special consideration to education in aircraft design -- realizing that this compact field contains all the basic design problems and hoping that a special effort can bring practical results.

APPENDIX I

PROFESSIONALISM

After the role of design as the intial stage and the essence of engineering has been discussed, some further aspects of a professional engineering education can be considered. First of all, what are the implications of professionalism ?

The need for recognized standards in engineering education is generally accepted. The role of the Engineers' Council for Professional Development was pointed out in Appendix B.1.7 and it was seen how a new emphasis on design as an integral part of professional engineering education is developing.

There is also the National Society of Professional Engineers which is concerned with all aspects of professionalism. It was established four decades ago and has been quite active promoting professional development, status, and recognition. In the educational field it is interested in professionalism not only with respect to technical competence but also regarding ethics and integrity essential to a profession, service to the public, and continued professional growth.

A completely new aspect of professionalism, however, has been introduced by the Educational Development Program outlined in Appendix B.1.4. As outlined in Ref. 22 and expanded in Ref. 59, beyond the client-oriented aspects of the professions the public-oriented responsibilities are of special significance. They are characterized by a recognized responsibility for the decisions which affect the quality of some significant portion of the public environments. The distinct flavor can be recognized by quoting some pertinent excerpts from Ref. 22:

"Within the university, the separate existence of the professional schools cannot be justified on the basis of the search for truth. The professions can draw support only from the American tradition of service to the community.... It seems only reasonable then to assume that the prime responsibility of the professional school must be the preparation of men who will understand and discharge the obligations of the profession. It is obvious that this entails the design of educational programs that offer preparation for a life of action and responsible decision-making...

"Actually, the practitioners of the professions are neither scientists nor artists, because all professionals are concerned with variations of the decision-making discipline. This discipline the engineer has called Design.... Design is a logical man-created process with a methodology that is closely akin to mathematics. We have defined design as an 'iterative decision-making process' used to optimize the value of man's resources.... The recognition of the professional as a logician who is skilled in the strategies of decision-making is important to the design of

professional curricula...

"The ultimate educational challenge to the professions is to insure the development of a system of higher education to produce the educated professional men required to serve society.... For the student of the professions, the humanities and social studies can and must become the most stimulating part of his undergraduate program, since he needs them not only to make him a better citizen and a fuller man, but to form the all-important value-foundation for professional decision-making...

"For the professional we reject the concept of a stratified college experience of two or three years of liberal education followed by two or three years of specialization. Instead, experience causes us to conclude that a four-year undergraduate program with the major elements proceeding in parallel and constantly reinforcing each other is pedagogically sounder and intellectually more stimulating. We particularly recommend that the introduction to the professional decision (design) processes be made in the freshman year. Through such a mechanism the student can fully appreciate the relevance of all of his future studies. The stimulation that this type of introduction has given the student for both his humanistic and professional studies has been especially gratifying."

This line of thinking is highly significant with respect to professionalism. It reasons that knowledge is not sufficient for a professional outlook. Inseparably connected with technical competence must be the skill of making methodical decisions, using the criteria of a recognized value system.

An obvious conclusion can be drawn regarding the need to incorporate meaningful courses in humanities and social studies in engineering curricula. They form the basis of a value system which is required for decision-making, for needs analysis, for impact analysis -- in short, for any responsible action going beyond purely technical details.

Humanities and social sciences are well enough entrenched in engineering curricula by now. As discussed in Section B.1.3, it is not a problem of providing more time for these subjects but a problem of making these subjects more meaningful to engineering students. Project work is more important than survey courses. Much trail-blazing work was done in this field, too, in connection with the Educational Development Program at UCLA. "Every substantial engineering problem can be solved, after all, only in the unique terms of the value system derived from the particular society in which the problem itself resides" (Ref. 60). A good deal of proselytizing still has to be done among engineering faculties. The subject is nearly inexhaustible and will not be followed up in the present investigation.

Another far-reaching conclusion can be drawn from considering the decision-making process as the basis of any professionalism. If non-engineering professions are concerned with the same decision-making process which is a fundamental part of the engineering

education, then a good engineering undergraduate curriculum may stand in good stead as a preparation for many a profession.

This meets with considerations along a similar line of approach which is taken as the theme of an entire issue of Engineering Education (Ref. 61). Medicine and law, for instance, require four years of general undergraduate education before the student is accepted in the professional school. Only slightly more than a sprinkling of these students at present comes with an engineering background. The percentage can be increased greatly and, indeed, expanded into a good number of other professions.

There are the fields of public service where decisions about energy distribution, natural resources, and application of technological innovations have to be made; urban management where interdisciplinary problems of a technological nature arise; management in general where the precise, quantitative thinking of the engineer is an excellent preparation; or educational technology where system principles are applied to teaching and learning problems.

In these fields a combination of liberal and engineering undergraduate education is needed. Liberal education provides the foundation to develop a value system which is necessarily qualitative and subjective by its very nature. Engineering education is based on precise, quantitative, objective thinking. Neither the liberal arts college nor the engineering college have established the ideal mix. Yet it appears that engineering colleges have recognized the problem more clearly. They provide about 20% in their curricula for humanities and social sciences while liberal arts colleges hardly touch problems of technology.

There is an enormous challenge in developing a truly liberal education for a technological world. This includes closing the gap which has developed between liberal arts on one side and science and technology on the other side. An important step consists of understanding clearly what both sides have in common.

The engineer plays a leading part in shaping our world of technology by solving technical problems. Only recently he has recognized that even the most sophisticated analytical problem-solving techniques do not suffice unless he combines them with a synthesis approach and the corresponding design attitude. The core of design lies in the decision-making process which cannot function without having established a value system. For any major engineering project this value system is concerned with the relationship between individual and society -- and we arrive in the field of humanities and social sciences.

All this is nothing new. In varying degrees everyone is aware of the complex of problems in this field. What is new, however, is that at the present time the multitude of problems seems to fall into their proper places. We can recognize the overall picture and see what problems have to be solved in the specializations of science, technology, operations analysis, humanities, and social

sciences as parts of a greater entirety. The proper perspective can be gained by the experienced specialist as he grows beyond his field of specialization or, coming from the other end, by the student or young faculty member who is concerned about relevance and establishes his reference frame of interdisciplinary relationships before he becomes a specialist.

Starting from the interpretation that the responsibility for our environment rests with the decisions made by professionals and that mastery of the decision-making process distinguishes the professionals in various fields, this brings us back to some basic considerations. To be a good diagnostician, a physician must have knowledge and understanding in a broad field and make decisions before he refers the patient to the specialist. The same relationship exists between designer and engineering specialist. Decisions have to be made in many fields and on many levels to determine the proper task for the specialist. In many cases decisions can be made intuitively by the expert. Professionalism, however, comes into its own with the ability to attack any problem in the field, independent of content or context, and to make logical decisions under complex conditions.

Professional engineering education can be approached in many ways. From the viewpoint of aircraft design there are some particularly interesting implications which open new perspectives. An undergraduate education in aircraft design offers components which may be important as a pre-professional preparation for many other fields, e.g. fluid mechanics, synthetic materials, or electronic instrumentation for medicine; energy, natural resources, or complex interrelations for patent law or public administration; light-weight structures and drag reduction for transportation systems; or quantitative thinking and system approach for any professional decision-making.

These are potential side-products of an education in aircraft design. The essential outlook is the same for the future aircraft designer as for the future professional in many an other field: An emphasis on using the methods of decision-making as practiced in engineering for solving complex problems. It is a professionalism which goes beyond any narrow specialization. Beyond this, it contains a concept of professionalism which can serve as a unifying link between all professions and which can provide a general basis for integrating many special viewpoints.

These considerations come also close to the general concern which is felt by many engineers regarding their professional status and public image. It appears that at the root of the problem is the question: is the engineer just a technical specialist or is he also educated to make important decisions of a broader nature ?

APPENDIX J

CONTINUING EDUCATION

J.1 Introductory Remarks

Continuing education in engineering serves the general purpose of protecting society's large initial investment in engineering education from rapid deterioration. The field of continuing studies has assumed enormous proportions but is still poorly coordinated. Available space in this report permits not much more than a summary of fundamental ideas, and other references have to be consulted for a more comprehensive picture. A good and concise survey of the whole field is given in Ref. 62. A basic effort which was made in 1964 to coordinate various segments interested in continuing engineering studies is described in Ref. 63. More recent developments in the field are published in a series of yearly conference reports. They are sponsored by the Continuing Engineering Studies Division of ASEE (Ref. 64).

Continuing engineering studies are, of course, not a new concept in a profession which has always been subject to continuous change and where the individual engineer becomes soon obsolescent unless he keeps abreast of new developments. Quite independent of any upgrading of one's level of education, there is a continual need for updating, diversifying, and broadening an engineering education. In earlier days continuing education took place in the form of unorganized and individual self-study. Now, with an ever-increasing rate of change in science and technology, an immense number of courses are offered, often initiated by the employer, often by universities, sometimes by commercial enterprises.

Beyond this slow evolutionary process, however, completely new and fascinating perspectives are opening up. They are likely to assume a fundamental importance for the structure of engineering education. Before discussing them, a very brief outline of some typical developments in continuing education related to aerospace and some basic considerations will be shown for general orientation.

J.2 Typical Examples of Continuing Engineering Studies

J.2.1 Regular Study Courses

Much practical pioneering work has been done at the Center for Continuing Education of Northeastern University. Practical in the sense that it was based on a clear survey of existing needs and available resources. Pioneering in the sense that new concepts have been carried out in a systematic way on a large scale.

The Greater Boston area is in the particular but by no means unusual situation that there is a combination of institutions of higher learning and a large industrial complex, much of it concerned with advanced technology and aerospace-oriented. A strong program of state-of-the-art courses was developed starting in the mid-1960s.

By the late 1960s about 100 courses were offered each year on a two-semester, non-credit, graduate basis, attended by about 1,200 engineers and scientists. More than half of them have master's degrees, about 30% hold doctorates. The courses are tailored to the needs of the practicing engineer in a rapidly advancing technology. Major fields of interest are system engineering, electrical engineering, applied sciences, computational sciences, and materials sciences. The technology of the area is moving so fast that few of the courses have been given more than twice. This situation is not basically different from others but a special concern for the fundamentals of continuing engineering studies has helped to establish many of the ideas which will be discussed in Sections J.3 and J.4.

An additional two-year experimental program was conducted at Northeastern in the late 1960s as Project GAP. It was designed to accelerate the process of bridging the gap between the knowledge which the graduate at the baccalaureate level has and the practical know-how which industry requires of him to become productive in an innovative sense on a specific job. An additional aim of the project was to start these recent engineers and science graduates on a lifetime regimen of continuing education.

Courses were initially restricted to six fields: electro-optics, computer technology and utilization, system engineering, biomedical engineering, semiconductor electronics, and materials sciences. A total of 44 courses was offered with a maximum of 15 students each. Participants in the program were required to be employed as engineers, to have received a degree in engineering or physical sciences during the last few years, and to commit themselves to take 2 courses during a given evening per week during 3 quarter terms of 12 weeks each. Thus, each student was required to attend class or workshop sessions for a total of 4 hours during a single evening per week for a total of 36 weeks. Homework requirements may have amounted to additional 4 to 8 hours per week -- a heavy but not excessive workload as a supplement to full-time employment.

Seventy per cent of the instructors were full-time employees of industrial or research organizations, 30% were from universities. The tuition of $100 per course, amounting to a total of $600 per student, was in addition to federal support of the project. The tuition fee was paid by the employer but some employers felt that this was more than they desired to spend on any one student. On the other hand, a program of internship for young engineers during their first year, as practiced by some large organizations, is more expensive by an order of magnitude. An important aspect of Project GAP is a careful evaluation of its effectiveness which includes a follow-up comparing the progress of participants in the project with non-participants over a number of years.

Other continuing engineering courses of Northeastern University are conducted as short courses at Henderson House of Northeastern University. This is a suburban estate where participants in special seminars or workshops study, eat, and live for periods

of a few days or a week. Laboratories are equipped with specialized equipment like electron microscopes and participants are drawn from all over the nation for brief but intensive work in a field of specialization.

J.2.2 Short Courses

The University of California at Los Angeles offers a large extension program with many continuing education departments. In engineering and sciences a great number of the evening extension courses are concurrent with regular UCLA courses, particularly on the undergraduate level. Others are on a professional level for the practicing engineer.

Of particular interest is the large range of short courses in engineering and sciences held at UCLA. A typical course lasts 5 days, is given by several lecturers, and provides a survey of new knowledge in a specialized area. Such short courses have become quite popular. It depends on the subject matter whether they remain on the level of surveying a wide field or probing a more limited field in depth. They are state-of-the-art courses, tailored to the needs of the practicing engineer just like the regular study courses mentioned in the preceding section and covering subjects in the same major fields. Generally speaking, this very concentrated presentation does not give enough opportunity for reflection, digestion, and formulation of precise questions but it provides an excellent survey of a field and a basis for further study. An important part of such courses consists of well prepared text and reference material. Much flexibility exists for attracting top lecturers and drawing participants from everywhere.

During the summer UCLA has been offering a six-week residential program on Modern Engineering for Engineering Executives at an off-campus location. Mathematical techniques, basic science, computer applications, and engineering systems are viewed from the standpoint of the executive who is responsible for research and development. This is an example for the many possibilities which the field of short courses offers.

Also mentioned should be the UCLA Engineering Executive Program. This is a unique 2-year program for mature engineers in responsible positions. It has existed for over a decade and leads to a Master of Engineering degree while the participants continue their professional work. Much emphasis is given to interdisciplinary design projects.

J.2.3 Courses on Closed-circuit Television

With distances and traffic conditions as they are in metropolitan areas, it is often difficult for the engineer to commute between his company and the campus where continuing education is offered. To overcome this obstacle, closed-circuit television was pioneered by the University of Florida in the mid-1960s and has been

adopted on a large scale by Southern Methodist University in the Dallas - Fort Worth area, by Stanford University in the San Francisco area, and by the University of Southern California in the Los Angeles area. The systems operate in the 2500 MHz band set aside for instructional television.

Regular classes are held on campus in studio classrooms, each equipped with two or three TV cameras with tilt-pan-zoom capabilities under the control of a student operator located in a glass-walled area at the rear of the classroom. A rear camera provides for close-ups of instructor and chalkboard. An overhead camera views notes the instructor writes or material he places on his desk. A third camera at the front of the room may be pointed at the audience. Students in the studio classrooms have small TV monitors to view material placed or written on the instructor's desk and they have microphones to transmit their questions or comments to remotely located classrooms. Monitors and microphones are usually placed between each two students.

The remote classrooms may be either within participating organizations or in regional facilities conveniently located close to high-technology industry. They are equipped with TV monitors and microphones to ask questions. Special FM radio transmitters in the remote classrooms provide response capability.

The Dallas - Fort Worth network links the studio classrooms at Southern Methodist University with several other institutions of higher learning as well as with industry, including large companies like General Dynamics, LTV, Texas Instruments, Bell Helicopter, Collins Radio, etc. Most of the courses are within regular graduate curricula. Off-campus students outnumber on-campus students and their majority consists of young engineers taking the courses for credit toward a master's degree. Others are auditors just interested in gaining knowledge.

At Stanford University the campus studio classrooms are linked to surrounding industrial plants. Regular academic programs are broadcast during daytime. For noncredit continuing education programs which are broadcast mostly in the evening, a nonprofit organization was set up to represent participating organizations.

The USC Instructional Television Center for the Los Angeles area was inaugurated in 1972, about 5 years later than the two previously described networks. In addition to four studio classrooms there is an auditorium equipped with cameras and control room to broadcast seminars and conferences to participating organizations. This is an important step. Special programs and technical conferences held on campus can be made available to personnel within companies either immediately or later by video tape. To facilitate employees from companies without TV-equipped classrooms in the neighborhood of Los Angeles airport, a regional TV-equipped facility with four classrooms is set up at El Segundo. This is within a 3-mile radius of more than fifty technology-oriented industrial organizations of various sizes.

Equipment for these types of closed-circuit TV courses is expensive. The installation of the USC Instructional TV Center cost $825,000, made available by a gift. Installation of equipment for one remote classroom with talkback capability costs about $7,000 which could be reduced very considerably if no talkback would be required. A $20 per unit television surcharge is imposed above the normal on-campus tuition for students taking off-campus TV courses.

It should be realized clearly that the one-way video format, in spite of the two-way audio capability, basically lends itself only to a lecture course. This can be effective for degree-oriented courses where well-established knowledge has to be transmitted. Continuing education for experienced professionals will frequently require a direct interaction among peers which does not develop when some are just one-way spectators of a TV set.

J.2.4 Mid-career Programs

A special situation may develop when a mature engineer has to assume completely new responsibilities. Some universities offer an opportunity for full-time study during a semester or a year which can be tailored to individual needs. The Center for Advanced Engineering Study at M.I.T. is an outstanding example.

Its advanced study program enables experienced engineers and applied scientists to work out their own individual programs in consultation with M.I.T. faculty. The entire spectrum of M.I.T. activities is made available, expanded by a number of special subjects and seminars to meet the particular needs of the Fellows of the Center, and enriched by the stimulation resulting from close association with other participants in the Program. The purpose is to prepare the participant for future responsibilities in his home organization and to serve as an intensive academic experience rather than a "refresher course". The Center has also developed several self-study subjects for use by practicing engineers and scientists as well as educators and students.

The primary requisites for admission to the Program are several years of professional experience, a record of past professional accomplishment, evidence of serious intent, intellectual maturity, and technical background. The Program fees are higher than regular student fees and when salary and other costs are added, the expenses for the sponsor are considerable.

J.2.5 In-house Extension Programs

A typical large aerospace company has a continuing education program with hundreds of courses. They extend over the full range from shop training to management development. These courses are developed and sponsored by industrial companies to assist employees in their work, contrary to the previously described programs originating with universities. The majority of company-sponsored courses are held after working hours, usually in the company's own educational facilities.

Many of these courses are sponsored by individual departments as they recognize specific needs. Such courses are directly applicable to company business and are given by experienced company personnel or sometimes by outside experts. Typical examples are courses to familiarize employees with the various systems of a new aircraft, or with computer programming, new technologies, computer graphics, or also with subjects which have been eliminated at many universities, like descriptive geometry.

Other company-sponsored courses correspond closely to university courses without being degree-oriented. They give an opportunity to emphasize applications and practical experience. The learner is motivated by the desire to improve his professional competence and also the teacher usually grows professionally within his company.

The extensive training programs for shop personnel should also be mentioned. They usually include manufacturing technologies like tooling, hot forming, chemical milling, welding, electrical soldering, drilling techniques, printed circuit repair, adhesive bonding, faying surface sealing, ultrasonic inspection, numerical control, template operation, and innumerable other specialties. A similar versatility may be offered in the field of electronics.

The magnitude of all these programs is most impressive. Guidance and counseling services are usally provided and career planning and educational development can be considered from a long-range viewpoint. Some companies provide special "certificate programs" for their engineers. The programs are designed to relate a series of courses to the objectives of a specific field, so that an employee may build on his prior education and experience to grow professionally and to keep abreast of new developments. Required and elective courses are combined to provide proper balance in fields like computer science, electronics, product design, industrial engineering, etc. A special certificate is awarded upon successful completion.

J.3 Some Basic Considerations

Continuing education is an open-ended process. Its purpose is not the attainment of an additional academic degree -- which means a terminal point -- although this may sometimes be a coincidental by-product. The purpose of continuing education is rather a lifelong process of improving professional performance and enriching one's own individuality. Both are often intricately interwoven. This has been recognized in recently evolving engineering curricula. They are often based on developing an understanding in psychology, sociology, history, ethics, and aesthetics as a background of the future engineer's professional competence before he is ready for random processes and decision-making. Should the present engineer, just because he is over 25 years old and often has not had meaningful college courses in subjects which later become of interest to him, remain deficient in these fields for the rest of his life ?

The most crucial aspects of continuing education have to do with motivation. As pointed out in Ref. 65, the engineer may be motivated by the desire to do a better job and to improve his position or also by the fear of not keeping up with young graduates and becoming obsolescent. He must think in terms of career planning. He may often have to overcome retarding influences like opposing demands on his time by work, family, or other obligations; or general inertia; or, quite frequently, a reluctance to expose himself to situations in which his knowledge or learning ability might be displayed adversely before a group of his peers.

There are other questions from the standpoint of the employer who often bears a major share or all of the expense. Is he over-educating the employee just so that he may lose him to a competitor who offers better opportunities ? Is continuing education just a fringe benefit to be considered as overhead or is it a real investment in human resources ? How can the interests of employer and employee be made to correspond one to another ?

All these problems have to be considered as an entirety. The engineer needs up-to-date education while industry needs well-educated engineers, and the profession and society as a whole are the principal beneficiaries of continuing education.

It must be recognized that teaching mature engineers is fundamentally different from teaching regular college students and it appears that only a limited number of regular faculty can effectively reach the practicing engineer as a learner. Katz shows in Refs. 66 and 67 very clearly the characteristics of continuing studies as well as the functional responsibilities of universities in continuing education. The students are professionals with mixed backgrounds and capabilities but with common interests. Typically they are eager to obtain specific knowledge directly or peripherally related to their work and they have a body of knowledge and experience which they are ready to share. Sometimes they have been themselves contributors to new concepts, knowledge, and practical techniques. This means that instructors have to be more than teachers and must be prepared to serve as resource persons in the widest sense.

This need for highly qualified "resource persons" as teachers in continuing engineering studies is in conflict with the realities of academic life. Not only is there an outspoken lack of scholars speaking the language of the practitioner, but administration and faculties usually take a dim view of full-time faculty members becoming involved in continuing education. As a consequence, the large majority of teachers in continuing education is drawn from professional practice. They remain separate from regular faculty and a good opportunity for communication between university and industry remains unemployed.

Basic and applied knowledge are closely interwoven in continuing engineering studies. Katz considers a knowledge-iceberg analogy, where applied knowledge is just the small visible part which pays off quickly but requires the support by the large underlying

structure of basic knowledge. Continuing engineering studies operate primarily on the upper or applied portion of the knowledge iceberg but have an inseparable effect on the submerged portion of basic knowledge.

There are many secondary but important practical questions connected with continuing education, like time, place, credits, and costs. Most frequently it is an after-hour activity but when the employer is sufficiently interested, it takes place on company time. Some universities schedule those graduate courses which are frequented by both regular students and engineers from industry in the late afternoon, and the engineers may have to leave their work an hour early. The courses may be held at a university, in the company, or at special learning centers.

Considerations about credits may easily become a nuisance. There is the more lofty ideal of accepting knowledge as its own reward compared to the more worldly realization that human beings strive for visible rewards, degrees, and pay raises. Frequently a "professional development certificate" is given after satisfactory completion of a course. Along similar lines, an experimental program supported by NSF is conducted at USC in Los Angeles which is aimed at industry personnel who believe that they have attained master's level proficiency by virtue of their own informal efforts and work experience. They will be awarded a "master's equivalency certificate" upon comprehensive examinations without formal coursework but they may also use televised courses from USC to become familiar with the material for which they will be responsible.

The cost of continuing engineering studies is generally not supported by public funds or private endowments. A state-supported university like UCLA charged in 1972 for a typical 12-week 2-hour course about $80 tuition fee, for a short course of 5 days with daily morning and afternoon sessions about $325. These costs are usually borne by the employer. For short full-time courses the additional costs for transportation, living expenses, and salary may impose severe budgetary restrictions on far-flung usage.

A new format, interesting both from the pedagogical and financial viewpoint, was tried out at the University of Washington (Ref. 68). It is designed for the needs and convenience of engineers who have been in industry ten or more years and who sense that the technical world is passing them by, that they are no longer prepared to take up graduate courses or to benefit from the short intensive courses given at an advanced level. Many are competent engineers who need new viewpoints.

Each course subject represents a modern approach not familiar to engineers of a decade ago. Courses already given at the University of Washington include Linear Systems Analysis, Computer Applications to Engineering Problems, Probability in Engineering, Structural Analysis, Semiconductors, and Electronic Circuits.

A typical course combines lecture, work-study, and correspondence modes. It may last 16 weeks with eight full days of combined lecture and work-study. Two different formats have been tried,

either using four two-day weekend sessions spaced four weeks apart or using eight alternate Saturdays and leaving Sundays free. Each morning and afternoon session starts with a carefully prepared group lecture to more than 100 participants, well prepared with modern public address system, two overhead projectors, and handout text material. This is followed immediately by a work study session on a set of problems based on the lecture, progressing from very simple to more complex ones. Problems are taken up by the lecturer, with an overhead projector for explanations after allowing sufficient time for most students to have understood the problem and some to have completed it. Assistants are available for help.

A set of selected additional problems is associated with each lecture, some provided with answers for self-checking, others assigned as homework for the correspondence phase of the course. The homework assignments must be mailed by a given deadline, are read by student assistants, and returned by mail within a few days together with a solution sheet for further study if needed. Since the continuing education student is relatively isolated, an evening telephone service is provided, manned by graduate assistants who can help the student to get back on the right track. The record of achievement on correspondence study combined with a final examination determines whether the student has passed the course.

From a financial viewpoint this format is quite interesting, too. Such a course requires much careful preparation of text material and problems, involves several instructors and graduate assistants, and calls for full involvement. Pay for lecturers was deliberately made comparable with that received for regular university classes. This indicates the importance attached to the effort compared to the traditionally lower pay of typical night classes. Correspondingly, the courses must be designed to be of interest to a wide range of engineers attracted from a larger geographical area. A typical fee for a 16-week course including all course materials, services, and luncheons was $125 in 1971 and with an average enrollment of 175 engineers the courses have proved to be self-supporting as well as an effective approach to an important educational task.

J.4 Trends and Perspectives

There is no argument about the need for continuing engineering studies. Much is being done but the whole field is still in an early stage of development and concerted action is still missing. Let us summarize some pertinent points:

a. The rate at which new knowledge is generated and utilized will make it necessary to accord a fully recognized position to continuing engineering studies. These studies may be conducted at either an undergraduate or, more frequently, a graduate level and there will be three distinct stages in engineering education:

> first, regular undergraduate curricula to provide a solid foundation and a clear understanding of the techniques of analysis, experiments, and design for

entry into the profession at the basic level with the bachelor degree;

second, regular graduate curricula to provide additional depth and breadth for an advanced degree;

third, continuing engineering studies -- partly to update, upgrade, and refresh earlier knowledge but particularly to pursue professional development free from the constraints of degree requirements.

Degree curricula lay the necessary foundation and set professional standards. Continuing engineering studies help to form the individual engineer as his career pattern evolves.

b. The two different aspects of continuing engineering studies should be clearly distinguished. On the one hand there is the need for updating, upgrading, or broadening the general knowledge in basic science or technology which means conventional coursework in the fundamental and enduring theoretical principles as taught at universities. On the other hand, the desire to stretch one's competence in the professional field means a concern with applications, practical problems, and new technologies which may possibly become obsolescent soon or which may hopefully turn into new discoveries and new knowledge. This goes beyond the traditional role of universities.

c. The principal means of continuing engineering studies, in addition to self-study, consist of regular university courses, regular in-house courses, intensive short courses, and mid-career refresher programs.

d. One of the elementary functions of continuing engineering studies is to supplement and broaden the experience gained by on-the-job learning and to bridge the gap between theory and practice. Reference 67 gives examples for the resulting "stretch-out courses" regarding the state of the art. A well-designed course brings to life the knowledge developed by researchers and the experience gained by practitioners in a specialized field. For the newcomer in the field the period of learning and familiarization is shortened, interest in the work is heightened, many mistakes can be avoided, and both employer and employee profit directly.

e. A higher function of continuing engineering studies is to support and stimulate the engineer as he is reaching into new realms of knowledge. New knowledge frequently emanates from engineers meeting the challenges in industry. This type of situation is discussed in Ref. 66 and 67: "What better way can there be for harvesting and distilling such new knowledge than by bringing together a group of knowledgeable contributors to advances in a particular field for a round-table learning experience and giving them an opportunity to share their knowledge and exchange their views concerning some new area of inquiry or intellectual activity ? When such a group is assembled in the presence of an instructor

from academia, he is in a position to benefit far more than any one of the other participants and can bring back some of the new knowledge acquired in this process to his formal educational activities."

Under these conditions the course becomes a seminar or symposium or workshop. Each one of the participants is simultaneously learner and "resource person". Such a situation is highly stimulating and rewarding for mature professionals.

f. Continuing engineering studies can easily be tailored to special conditions when professionals have to be converted to new fields, updated about new developments, or reoriented toward managerial responsibilities. Recent cutbacks in aerospace provided many examples for the need of professional reorientation. Under these conditions the participants often form a particularly non-homogeneous group with widely varying backgrounds.

g. From the viewpoint of the university, the existence of continuing engineering studies harbors the promising potential that pressure on the undergraduate curriculum may be reduced and more flexibility for the student may be provided. Regular curricula can furnish the fundamentals while continuing education can take over the concern for practical know-how and application -- an old objective which has seldom been accomplished. Pressure on the curriculum is reduced when there is no need to prepare the undergraduate for the full spectrum of professional life. Flexibility for the individual is provided when career decisions can be postponed until the professional career takes shape and the engineer is in a position to judge himself what specific educational needs he has.

h. The report on Goals of Engineering Education anticipated that a fifth year at graduate level will soon be required for a basic professional degree. This was in the late 1960s. Since then there has been a considerable drop in engineering enrollments. The rigors of engineering curricula are believed to be one of several major reasons. As a consequence there is not so much thought at present about extending the basic curriculum to five years. Instead, there is a general trend toward reducing the four-year curriculum from about 210 quarter units to about 180. It may well be that continuing engineering studies provide the answer to the dilemma shown in the first paragraph of Appendix B.1.2.

i. All the promises which continuing education holds must not make us lose sight of an inherent predicament. The dynamic nature of engineering imposes a lifelong challenge on the engineer. He will respond to it and meet it as long as he dedicates himself to his task and is able to grow and to remain young in spirit. If he should settle into a dreary routine and lose his initiative and mental alertness, no continuing education would be meaningful any more. The key will be provided by the motivation which the engineer has for developing his own resources -- and this calls for support from employer, professional society, and social climate.

APPENDIX K

EDUCATIONAL MEDIA, METHODS, AND CONTENT

K.1 Introduction

It has often been remarked that our educational system has remained virtually unchanged for five centuries after the invention of the printing press. When more than three centuries ago, in a Europe ravaged by the 30 Years War, Comenius made a valiant effort toward change, suggesting that teachers should teach less and learners should learn more and that this could be accomplished by better learning methods arousing students' interest, the time was not ripe for it.

At long last a radical change began in the 1950s. Skinner's interest in "teaching machines" stirred up a lively controversy (Ref. 69). An abundance of ideas emerged during the 1960s and has resulted in much confusion particularly about new technologies.

A clear and concise survey of instructional technology in higher education can be found in a recent publication by the Carnegie Commission on Higher Education (Ref. 70). The present developments in instructional technology are viewed as a fourth revolution in education, after the first revolution occurred when education was shifted from parents to teachers and from the home to the school, the second when writing was introduced, and the third when printing brought about wide availability of books. This provides an appropriate and quite fascinating perspective.

K.2 Educational Media

In spite of this appreciation for a revolutionary situation, Ref. 70 takes a very balanced view of educational realities. The unbridled enthusiasm of the mid-1960s about new ideas seems to have subsided in recent years and the difficulties of accomplishing fundamental changes are recognized. Consequently, a gradual development is forecast for informational technology in higher education, with a penetration of perhaps 10 to 20 percent <u>on</u> campus and 80 percent or more <u>off</u> campus by the year 2000. (A reservation should be added that extrapolations over a quarter of a century are risky and the time scale depends, among other things, on the still-unknown attitude of a new generation of faculty).

An enormous investment has been made in experimentation and research with instructional technology in the United States. Yet the present situation is largely uncontrolled, without much coordination and planning. Reference 70 points out the great need for higher education to assume a role of leadership and sees the principal obstacles in the lack of institutional commitment, the apathy or even resistance of faculty members, an expectation of immediate cost-savings while these savings should be expected only in the long run, a grossly inadequate supply of good quality instructional materials, and incompatibilities in the design of instructional components.

A full consideration of instructional technology would exceed the scope of this report. The subject is covered and a list of references is given in Ref. 70. Only a survey of characteristics and approximate costs of various instructional media is given in the table of Appendix L which is taken from Ref. 71.

Within the framework of this table, additional emphasis should be given to the role of cassettes. Audio tape cassettes and recorder/playback units have the advantages of easy availability, simple handling, relative inexpensiveness, compactness, and portability Video tape cassettes with player units which can be attached to any television set are still expensive but their wide-spread use within several years may be anticipated. In addition, carrels for listening to audio tapes and for viewing audio-video tapes on TV have become standard installations in many college libraries.

Many of the educational media find an earlier introduction and wider application in off-campus activities. Continuing education, as shown in Appendix J, is one example. An entirely new field is developing at present under a variety of names: external, extended, or extramural education, nontraditional study, open university, or university without walls.

We may summarize the large field of educational media by simply stating that a large arsenal is basically known and available but that much of it is poorly written up and not yet reliably evaluated.

K.3 Educational Methods

The initial wave of interest in teaching machines and gadgetry which was typical of the 1950s soon gave way to a more basic concern about educational methods. New ideas to replace the traditional lecture method began to mushroom and finally resulted in a confusing array of names like Programmed Instruction (PI), Self-paced Instruction (SPI), Keller Plane or Proctorial System of Instruction (PSI), or Individually Prescribed Instruction (IPI). An outline of the Keller Plan, which is particularly representative of this group, is given as an example in Appendix M.

Since it is our purpose to find out about basic educational trends which may be significant for aircraft design, we can leave out many details and focus on essentials. It appears that most of the new methodology is based on the four principal concepts of programmed learning, self-paced study, course objectives in behavioral terms, and motivation. They may first be discussed separately.

Programmed Learning has the following characteristics:

- The learning process is broken up into discrete steps which are comparatively small, carefully sequenced, and precisely organized. Each of these steps must be reinforced and mastered before the next one is taken.

- The student is an active participant, not a passive reader or listener. His mind must constantly interact with the

subject matter by being challenged to respond to questions for which an immediate feedback informs the student whether his response is correct.

- The sequence of steps may form either a "linear" or a "branching" program. In a linear program the sequence remains the same no matter what the student's response. A branching program becomes important mostly for the special case of computer-aided instruction. It contains a series of multiple-choice questions and each wrong response leads to a different remedial sub-program.

- Programs are basically in form of a written workbook but may also be in form of an audio or audio-visual tape or a computer-controlled program. Their preparation requires careful attention to the logic and psychology of learning.

- Programmed learning serves the purpose to free the teacher from the routine of transmitting available information where he sometimes performs not at his best and where a meticulously prepared program can do as well or better. The program can make the teacher free for his higher tasks of stimulating and guiding students, conducting seminar-like sessions, responding to questions, and discussing applications and implications (Ref. 51).

<u>Individual Study</u> is based on three basic ideas:

- Each student should learn at his own rate. This is quite different from the usual classroom teaching which is directed at a non-existing average and where some students may be a step ahead while others have not grasped the last point yet.

- Each student should be responsible for his own learning. This serves as a psychological challenge. The teacher is available for advice, assistance, and guidance.

- Each student should be provided with a detailed study guide, providing him with a step-by-step sequence for his studies and giving references to the best and most up-to-date study material available for each step.

One version of self-paced study is discussed in full detail in Ref. 72.

<u>Course Objectives in Behavioral and Measurable Terms</u> define the type of behavior that students are expected to demonstrate at the end of the learning experience (Ref. 73 and 74). Such statements, going into considerable detail and provided at the beginning of the course, offer much clarification and direction to teacher as well as student. The basic approach, as shown in Ref. 74, is taken in two steps:

- State the major instructional objectives in terms of learning outcomes. Use verbs which are general but provide direction,

i.e., to know, understand, recognize, apply, judge, etc.

- State each specific learning outcome in behavioral terms. Use verbs which express observable student behavior, e.g., to define, describe, identify, select, explain, predict, compute, differentiate, formulate, generate, operate, etc.

Instructional objectives can be identified and defined within an overall scheme of cognitive, affective, or psychomotor domains. For the correlated learning outcomes a distinction can be made between a "minimum-essentials level" where student behavior fits a well-defined minimum level of performance, and a "developmental level" where each student is encouraged to progress as far as possible toward predetermined goals. This will help students to identify their own strengths and weaknesses in learning and to develop their self-evaluation skills.

Within a few years in the early 1970s the importance of detailed course objectives in behavioral terms gained general acceptance. It imposes a new kind of effort on the teacher but it pays dividends to him as well as to the students throughout the course.

Motivation of students has not received as much consideration as it deserves. Some basic aspects as shown in Ref. 75 will be mentioned:

- The average student encounters not only little motivation but also outspoken demotivating factors in the university. Inadequate mastery of prerequisite courses (cumulative ignorance), low-level faith in his abilities, poorly defined goals, and lack of perspective rank high among demotivating factors.

- Motivating forces can be provided for the student by independent work as well as team work, opportunity for critical and creative thinking, realistic problems relevant to professional practice (e.g., case studies), involvement in the teaching process as a proctor, or by teachers who have enthusiasm, professional stature, or personal characteristics to inspire the student.

- The high attrition rate among engineering students during the freshman year is largely caused by a lack of attention to the need for motivating students.

After this very brief but essential outline of the separate characteristic aspects of programmed learning, individual study, course objectives, and motivation, we are almost ready to put these elements together, compare them with the conventional lecture method, and discuss the resulting educational methods. Before we do this as part of the overall considerations in Section K.5, let us take a brief look at the question of the content in engineering education.

K.4 Educational Content

Any discussion of media and methods must not obscure the basic

fact that they play only a secondary role compared to the content of engineering courses. Two different interpretations of the word content are found in the literature in this connection. Both are significant but a distinction should be made. One of the interpretations is concerned with the selection of the subject material to be taught, the other one is concerned with the quality of educational material presented to the student.

The first interpretation is considered in Ref. 76. Selection of the optimum content for a given course requires a teacher who is fully competent in the subject and keeps abreast of new developments. He must also be familiar with the overall curriculum and the students' maturity, their background, and future needs. He has to use his professional expertise to select the appropriate topics, their relative importance, and the corresponding degree of coverage. He also has to assess the level of competence which his students may be expected to attain. Finally, a set of measurable objectives should be delineated as evidence of acceptable student performance.

The second interpretation is considered in Ref. 77. In this context, content is understood to include all educational material available to the student, i.e., textbooks, handout notes, programs, tapes, study guides, etc. Lectures, experiments, or one-time showings of films may be considered in a slightly different category but very closely related. Meticulous preparation of educational material is of greatest importance. The teacher who prepares this material has to put himself completely into the shoes of the student, understand his outlook and his thinking process, and know about learning psychology. Usually this takes many trials and errors.

K.5 Summary of Media, Methods and Content

K.5.1 Where do we Stand ?

On the one hand, educational media provide us with a new instructional technology which offers much promise but requires considerable investment of time and frequently of funds. On the other hand, considerations of educational methods and content provide us with a growing insight into the learning process but we are still in an early phase. It is a challenging situation. On a large scale and with new resources we are trying to solve the multitude of problems which have always existed in every college course. We have to tread carefully in the realm of the unproven, but action is needed as soon as we feel sure about it.

From a somewhat simplified viewpoint, many new media can be considered to be practical and available and their introduction depends on cost, effectiveness, and attitude in each case. With respect to methodology, we may think of three different aspects:

Firstly, the need for programming in connection with "teaching machines" made it mandatory to pay much attention to the learning process. This has had a very salutary influence. The programmer had to put himself in place of the student and the characteristics

of programmed learning, as outlined in Section 10.3 were the outcome. They also have had a decisive influence on improving the clarity of textbooks. The lesson was learned quickly and many recent textbooks present new concepts in small, concise packages, reinforcing them with illustrative examples and reviews. Such a well-written textbook, in turn, may make "programmed learning" superfluous.

It should be realized that a recorded program -- no matter in what form -- is frequently superior to the lecture method simply because much greater care is taken in its preparation than in the usual preparation of a lecture. The line of thinking and the pedagogical talents of the program's author always remain open to the scrutiny and criticism of peers and students. No wonder that only the best survive.

Secondly, individual study with clearly established standards of achievement has the consequence that "learning becomes the constant and time becomes the variable" (Ref. 72). This has enormous implications. Combined with programmed instruction, the teacher is no longer the dispenser of knowledge but becomes primarily the diagnostician of learning problems who recognizes the student's individual needs and who also stimulates seminar-type discussions. This is, however, still a distant goal for the majority of undergraduate courses.

Thirdly, most of any new methodology, including course objectives and motivation, is hardly very different from the intuitive understanding which a gifted teacher has always had. When Aristotle taught Alexander more than two millennia ago, he undoubtedly used many or most of the principles incorporated in programmed learning and individual studies. The goal is to make this level of excellence available as a recognized general standard. Intelligent use of instructional technology may serve as a means to an end. This is the realistic goal of effectiveness in teaching and learning. It can be recognized clearly and it is almost within reach.

K.5.2 What is Being Done?

Converging toward this realistic goal, the diversity and cost of educational media might be frightening at first sight. This should not be. We can easily see that a course on any engineering subject may increase its effectiveness in small steps.

For instance, a course on circuit analysis was given as a conventional lecture course a number of years ago. When a good self-study program on Laplace transforms became available, this was incorporated in the course to replace a week of teaching. During this time class meetings are suspended while students study this somewhat intricate mathematical tool on their own, each spending as much time as he needs. The teacher is available for questions and at the end of this period an examination on the subject is given. A few years later, a good self-study text on the oscilloscope made it possible during the laboratory sessions to leave this subject -- which is new to some students and familiar to others -- to self-study. Later again, as the shortcomings of a

conventional course outline would be recognized, it could be replaced by detailed course objectives in behavioral and measurable terms. Every teacher can find similar examples for gradual improvements.

Obviously, good educational media are preferable to a poor teacher. On the other hand, a small class with an outstanding teacher who has time to prepare himself should be preferable to educational media. Between these two extremes there are many border cases where the decision is not easily made.

This indicates how important it has become for the teacher to be familiar with the possibilities offered by educational media and methods, their advantages and disadvantages. First of all, there is much evidence for the basic conclusion that many methods and media exist by which a student can learn equally well. For instance, no general conclusions are available that students learn better by listening to a lecture in a classroom than by having the same lecture on TV, or whether self-paced or group-paced learning is preferable. It appears that for each individual case decisions have to be based not only on quality but also on many additional parameters like teacher's experience, students' personalities and circumstances, availability, costs, etc.

Recent investigations indicate that C. G. Jung's theory of psychological types may be related to the student's learning traits (Ref. 78). Psychological types are based on differences which can be measured by four pairs of preferences: direction of interest as extroversion vs. introversion; perception as sensing vs. intuition; judgment as thinking vs. feeling; and life style as judging vs. perception. It is not yet certain whether this is the right track but more research in this region will provide some of the missing links with respect to the learning process.

The variety of educational media and methods provides a healthy competition for the traditional lecture method. Many lectures can be greatly improved by thorough self-examination to overcome the handicap of most engineering faculties, namely that they have never been educated to be educators. It is not enough for a teacher merely to display his knowledge on the chalkboard or to mumble and mutter in front of a class. The "mirror effect" of videotape recording with playback and the ease of arranging this has been helpful to many instructors for improving their teaching skills. How many sins are committed daily against the basic tactical rules of using the first and last few minutes of a lecture period for introduction and summary ! How often does the teacher "not find the time" to prepare good lecture notes or a course outline in behavioral terms ! How easily does he overlook the aid he could get from a simple tool like an overhead projector ?

The teacher is responsible for selecting the appropriate methods and media. Quality, effectiveness, availability, and costs are major criteria. Most important, there is no substitute for quality. This means time for preparation. Whether it is the comparatively short time of preparing a lecture or the much longer time of

preparing programmed instruction, this overhead time must be amortized with respect to the number of students who benefit from it -- either immediately in classroom or self-study or, in the case of programs, spread out over many universities or repeated over many years. The very considerable time it takes to prepare a good tape or program must be estimated realistically and advantages of any innovation must be clearly demonstrable.

Educational material has to be of high quality. Its effectiveness has direct bearing on the student's learning process, but beyond this the teacher wants to be justifiably proud of it and the student will be affected by it in the habits and attitudes he develops. Professional standards must obviously be met by any material which has wider circulation. Some liberties, however, can be taken for limited purposes.

A typical situation frequently develops in laboratories. An introductory lecture to explain purpose, equipment, operational procedure must often be repeated for several class sections and over many terms. This becomes a bore for the instructor, the clarity of presentation may suffer, demonstrations are often seen only by a few students standing nearest, and an unsatisfactory experience is the result. So why not put it on a simple tape-slide program ? An amateur production can be fully satisfactory as long as it provides clarity. 35 mm color slides are combined with an audio tape. A combination of carousel projector and audio-visual programmer makes the presentation fully automatic and synchronized. This is inexpensive and can easily be modified or updated at any time.

Every teacher knows similar small-scale examples where instructional technology can be useful. There are many concepts which the student really grasps only when he is exposed to them a second or third time after he has thought about them. Textbooks are often not quite satisfactory. We learn best when more than one human sense is excited. Equations, derivations, definitions, sketches, and brief notes can be put on handouts for the student to see, while explanations and implications are better put on an audio tape for the student to hear. Such combinations of handouts and audio tapes are a powerful and inexpensive conbination. Any teacher can prepare them and many are available commercially. AIAA, for example, has had special lecture series to keep engineering specialists up to date and published them afterwards as a combination of audio tape and notebook containing equations, figures and references.

Textbooks are, of course, of greatest importance. The problem has always been that each faculty member has somewhat different desires, that it takes a long time to write and publish a textbook, that it is expensive, and that contents and arrangement may soon become obsolescent. Reference 79 describes a new trend of "demand publishing". Low-cost reproduction makes it possible to put together material from the most diversified sources at a cost of only about 2.5 cents per copied page. When reprint permissions are obtained, a professor can select material from various textbooks, journals, research reports, or classical writings, add some notes of his own and a table of contents, and have it

published as a soft-cover edition of as few as 100 copies in as little as six weeks.

Films are particularly useful to demonstrate complex physical phenomena. Much pioneering work was done in the 1960s when the National Committee for Fluid Mechanics Films, supported by the National Science Foundation, produced a great many films and film loops in fluid mechanics. A good example is the series of four films on Fluid Dynamics of Drag, each about 30 minutes, with an accompanying text in the form of a paperback book (Ref. 80).

Film loops are short silent films, each about 4 minutes, designed for use with an instant movie projector which requires no threading or rewinding. Each loop illustrates a specific concept and is easily incorporated in lectures or laboratories or is available for independent student viewing. All this material is distributed by Encyclopedia Britannica Educational Corporation.

In the field of undergraduate education the needs and potentials are particularly great. Courses in fundamentals face the same problems in all universities. Exchange of ideas, innovative approaches, and textbooks and other commercial products find a large market. Much is going on in this field but coordination seems to be lacking. The previously mentioned fluid mechanics films are a shining example for the contribution which a well-directed effort can offer. Other examples are the self-study programs of the Center for Advanced Engineering Studies at M.I.T. which include packaged refresher courses for practicing engineers on subjects like Calculus Revisited, Nonlinear Vibrations, Probability, Random Processes, etc. Each contains about two dozen lectures on film or video-tape, with study guide and supplementary notes, representing a considerable effort and correspondingly expensive.

It would be impossible to list all the work going on in this field. Yet there is much room for creative contributions and particularly for organizing talent. Much can be learned from the systematic approach taken by the British Open University (Ref. 81). It combines a search for new methods and media with a true interdisciplinary and interprofessional outlook. Much of the material produced by the Open University becomes very attractive to other educational institutions, both academically and economically.

The field of aircraft design deserves special mentioning because it offers many new possibilities which have not been explored yet. Much government-supported research is conducted in widely distributed places. Recent difficulties in the fields of fatigue, stress corrosion, fracture mechanics, and others indicate how useful it could have been if newly acquired knowledge and experience would have had wide and early distribution in industry and at universities. Both continued education and regular university courses can profit greatly from educational programs in the fields of developing technology. A small percentage of research funds channeled into such educational programs can contribute much to consistent developments.

K.5.3 Where are we Going ?

As stated in Ref. 70: "Expanding technology can enrich the content of students' learning experience, provide greater flexibility and variety in the organization of instruction, and give students a more self-reliant role in their own education.... We are confident that the expanding instructional technology will improve learning, make learning and teaching more challenging to students and teachers alike and yield cost savings as it becomes more widely used and reduces the need for live instruction..."

Accordingly, Ref. 70 urges early action toward quality instruction, production of more learning materials, assumption of initiative and leadership by colleges and universities, and establishment of cooperative regional learning-technology centers.

The principal obstacles have been summarized in the second paragraph of Section K.2. Promise and obstacles have to be balanced against each other and future trends are indicated by practical problems which have to be solved. Let us review some considerations which are of interest to engineering faculties:

a. The potential of educational media has not yet been acknowledged by faculties in general. Media are in the process of changing the role of the faculty member. They provide the means that he can develop from being an instructor into becoming an educator, freeing him from routine instruction to make him available as counselor and leader of discussions and seminars.

Unfortunately, as stated in Ref. 70 and supported by much evidence: "The apathy and, in many instances, the resistance faculty members feel toward the adoption of new instructional technologies have deterred colleges and universities from moving confidently into a leadership role." This is a severe indictment. Against this background, each faculty member will have to make an honest assessment of his individual position within a changing situation, recognizing the wide range of options which exists between conserving what is best in traditional methods and exploring the potential of innovations.

A gradual process is taking place, consisting of many small steps. Initiative and enthusiasm are required for anything new but they have to be blended with much prudence and caution to make sure whether the new is better than the old. Change just for change's sake is a folly which is too expensive.

b. The implications of the changing situation with respect to educational media and methods must be considered from a long-range viewpoint within each faculty. A proper course of action will be influenced by personal attitudes and available resources as well as institutional encouragement and incentives. Time must be invested before instructional technology can yield any dividends and this has to be recognized in planning. Ref. 70 makes the special point that the impact of declining student enrollments can

be reduced by using faculty time for revision of instructional material in anticipation of future rises in enrollment and that the fear of media immediately replacing the professor is ill-founded.

c. Much instructional technology has been developed as the outcome of a considerable effort but there is a great discrepancy between availability and use of educational media. Without instructional materials the media are of no use. The greatest need is for creating and using instructional materials of superior quality. Small instructional units provide much flexibility and single-concept programs have great merit. They may originate with individual faculty members, with institutions, or with commercial organizations. This is mostly a question of organized initiative, and the field is wide open. The student will increasingly expect highest quality, no matter whether he learns from a lecture or from an instructional unit prepared locally or obtained commercially. The young generation is used from their home TV set to be exposed to the best people in a field.

d. The greatest impact will be felt in undergraduate courses. There is little doubt that the very high rate of attrition in engineering freshman classes can be improved considerably by educational media and methodology. Psychologists still have to find out much about the learning process. As a practical approach, a proposal is made in Ref. 75 to put a profession-wide effort into designing the most efficient way to help students master the fundamentals. A group of top quality teachers from over the country would meet to discuss and define the unchanging fundamental principles every student should master for a given basic course. Full consideration would be given to educational psychology, theory of learning, media, communication, evaluation, motivation, etc.

e. This last proposal touches upon an aspect which should be emphasized: course design. This subject is explored in a series of articles by Wales et al. (Ref. 82). Any course firstly has to be related to the overall curriculum and secondly has to follow its own logic. A given input of students is to be transformed into an output with additional desired characteristics. This is a process of the same nature as the engineering design process we have considered in Appendix G. It takes the same approach with problem definition, analysis, synthesis, and optimization of alternative solutions. It certainly would be unworthy of an engineer to be satisfied with a course design which does not meet the basic standards of an engineering design.

APPENDIX L

CHARACTERISTICS AND COSTS OF VARIOUS INSTRUCTIONAL MEDIA

The table on the following pages is reproduced from Miller in Ref. 71. The first column shows 17 categories of instructional media. The following 9 columns give typical characteristics and the final column gives approximate cost data per user hour, including costs for both operation and depreciation. The wide range of costs indicates dependence on a great number of parameters, like utilization of equipment, student-teacher ratio, etc.

CHARACTERISTICS AND COSTS OF VARIOUS INSTRUCTIONAL MEDIA (1969) (Ref. 71)

Instructional medium	Can user carry it around?	Can user use it individually at school or college?	Can user use it individually at home?	Can user determine when it is to be used?	Can user control rate of information flow; repeat, if not understood?	Can user interact actively with input?	Is individualized "branching" possible?	Senses used	Can signals be sent on electronic network?	Costs (dollar per hour of use)
1. Class lecture	No	No	No	No	Rarely	No	No	Vision & Audition	No	0.15-3
2. Small discussion group	No	No	No	No	Sometimes	Yes	Rarely	Vision & Audtion	No	0.50-15
3. Books and journals	Yes	Yes	Yes	Yes, unless another user has it	Yes	No	No	Vision	No	0.05-10
4. Printed programmed instruction	Yes	Yes	Yes	Yes	Yes	No	Yes	Vision	No	0.05-10
5. Computerized programmed instruction	No	Yes	Rarely	Yes, unless number of terminals is limited	Yes	Yes	Yes	Vision & Audition	Yes	2-25

Instructional medium	Can user carry it around?	Can user use it individually at school or college?	Can user use it individually at home?	Can user determine when it is to be used?	Can user control rate of information flow; repeat, if not understood?	Can user interact actively with input?	Is individualized "branching" possible?	Senses used	Can signals be sent on electronic network?	Costs (dollar per hour of use)
6. On-line Computer aids to learning and scholarship	No	Yes	Rarely	Yes, unless number of terminals is limited	Yes	Yes	Yes	Vision	Yes	5-100
7. Closed-circuit lectures on public address system	No	No	No	No	No	No	No	Audition	Yes	0.02-2
8. Educational radio	No	Yes	Yes	No	No	No	No	Audition	Yes	0.01-1
9. Dial-access audio tape recordings	No	Yes	Rarely	Yes	In same systems	Rarely	No	Audition	Yes	0.01-2
10. Broadcast live instructional TV	No	Yes	Sometimes	No	No	No*	No	Vision & Audition	Yes	0.02-10

Instructional medium	Can user carry it around?	Can user use it individually at school or college?	Can user use it individually at home?	Can user determine when it is to be used?	Can user control rate of information flow; repeat, if not understood?	Can user interact actively with input?	Is individualized "branching" possible?	Senses used	Can signals be sent on electronic network?	Costs (dollar per hour of use)
11. Closed circuit live instructional TV	No	Yes	No	No	No	No*	No	Vision & Audition	Yes	0.03-3
12. Broadcast tape-recorded instructional TV	No	Yes	Sometimes	No	No*	No*	No	Vision & Audition	Yes	0.03-5
13. Closed-circuit tape recorded instructional TV	No	Yes	No	No	No*	No*	No	Vision & Audition	Yes	0.03-2
14. Dial-access instructional TV	No	Yes	No	Yes, unless number of terminals is limited	Sometimes	Rarely	No	Vision & Audition	Yes	0.50-5

Instructional medium	Can user carry it around?	Can user use it individually at school or college?	Can user use it individually at home?	Can user determine when it is to be used?	Can user control rate of information flow; repeat, if not understood?	Can user interact actively with input?	Is Individualized "branching" possible?	Senses used	Can signals be sent on electronic network?	Costs (dollar per hour of use)
15. Facsimile transmission of documents by electronic circuits	Terminals can be portable and attached to any telephone	Yes	Possibly	Yes, during hours sender is able to transmit to user	No	No	No	Vision	Yes	2-15
16. Automated storage and retrieval of written and graphic materials	No	Yes	Rarely	Yes	Yes	Sometimes	Yes	Vision	Yes	2-100
17. Other standard audio-visual aids	Usually	Yes	Often	Yes	Yes	Sometimes	Rarely	Vision & Audition	No	0.05-8

*Recent technological developments may remove these limitations in the future.

APPENDIX M

THE KELLER PLAN
OR PROCTORIAL SYSTEM OF INSTRUCTION (PSI)

As an example for a number of similar efforts, the Keller Plan is one alternative to the traditional lecture-discussion method of teaching (Ref. 83). It is based on the reinforcement theory of psychology, according to which behavior is altered mainly through its consequences. The aim is to maximize the rewards and minimize the punishments, anxieties, and frustrations in the educational situation for everyone involved. Quoting from Ref. 83:

"To implement the PSI method, course material is divided into units, each containing a reading assignment, study questions, collateral references, study problems, and introductory or explanatory material. The student studies the units sequentially at the rate, time, and place he prefers. When he feels that he has completely mastered the material, a proctor gives him a "readiness test" to see if he may proceed to the next unit. This proctor is a student who has been carefully chosen for his mastery of the course material...

"If the student does not successfully complete the test, he is told to restudy the unit more thoroughly. He receives a different test form each time he comes to be tested. No matter how many times a student is required to take a unit, his grade is not affected; the only interest is that he ultimately demonstrate his proficiency...

"The basic features of the PSI method are:

1. The go-at-your-own-pace feature, which permits a student to move through the course at a speed commensurate with his ability and other demands upon his time.

2. The unit-perfection requirement for advance, which permits the student to go ahead to new material only after demonstrating 100% mastery of that which preceded.

3. The use of lectures as vehicles of motivation, rather than as sources of critical information.

4. The related stress upon the written work in teacher-student communication.

5. The use of proctors, which permits repeated testing, immediate scoring, almost unavoidable tutoring, and a marked enhancement of the personal-social aspect of the educational process."

The Keller Plan became popular quite quickly and a majority of students taught by this method prefer it to conventional teaching methods. It eliminates the "lock-step" feature of other courses and can readily be improved from year to year by iteration. Two important conditions, however, must be met:

Firstly, the method depends on the availability of well-written text material. This makes it suited best to undergraduate courses, including those which involve problem-solving techniques.

Secondly, the method depends on the availability of student proctors. They have to be chosen carefully by the professor who must keep close contact with them. Proctors interact directly with the students, answer their routine questions but must be ready to admit the limits of their knowledge and to refer the student to the professor when needed. The ratio of proctors to students has been about 1:10.

APPENDIX N

SUPPLY, DEMAND, AND ECONOMICS

N.1 Economic Aspects

Any academic considerations about education in engineering have to face some very realistic questions: How many students will take this education, how much does it cost, and who will pay for it ? Readily available statistics provide a quick and sober answer about the present situation but this will open up a Pandora's box of additional questions for which there are no easy answers.

We may first consider some economic aspects as outlined in Ref. 84. The largest single component of direct cost in an educational operation is the direct instruction cost. For its practical measure an instruction cost index can be established as the direct instruction cost per student credit hour. This introduces class size as a major parameter. By the same token, faculty productivity in teaching can be measured in terms of student credit hours per faculty member which may be as important a factor in planning an engineering program as is teaching load. Care must be used, of course, in comparing undergraduate with graduate programs.

The data supplied in Ref. 84 indicate that an undergraduate engineering program should ideally graduate at least 40-50 B.S. recipients per year in each major. When this is the case, teaching resources can be deployed effectively for large sections of 40 - 50 students or two smaller sections each of 20 - 25 students.

An analogous situation exists at the graduate level where 40 - 50 M.S. degrees should be awarded annually in a given major. Otherwise, since most graduate courses are elective, class sizes would be undesirably small. If the graduate program has an adequate number of students and if it does not require a thesis, it is not necessarily more expensive than an undergraduate program. The expenses of faculty-student research activity are not ordinarily a major factor affecting the instruction cost index as they are mostly supported by grants and contracts.

Reference 84 leads to the conclusion that more institutions are offering undergraduate and graduate work in engineering than are needed. Of the institutions having ECPD-accredited curricula in 1965-66, only half of those awarding the B.S. and only a fifth of those offering the M.S. achieved the minimum level of activity required for economic operation as defined above.

A different aspect is introduced when continuing education is considered. While regular curricula are supported by public or private funds, at least to some extent, such support does not exist for continuing education. With the growing role which continuing education is bound to play for engineers, particular attention will have to be paid to the question whether and under what conditions public support should be provided for it. It appears that

the economics of engineering education will have to be considered from an overall viewpoint, including both regular and continuing education, just like the educational aspects. This is, however, beyond the scope of this report.

N.2 Engineering Aspects

As a background, the total number of all bachelor's degrees conferred by universities and 4-year colleges in recent years may illustrate the increasing role of higher education. After the post-war peak in 1950 with subsequent decline, there was a steady growth from 290,000 bachelor's degrees in 1955 to about 520,000 in 1966 and then, at a greatly increased rate due to the post-war population boom, to about 800,000 in 1970. This means a three-fold increase in about 17 years.

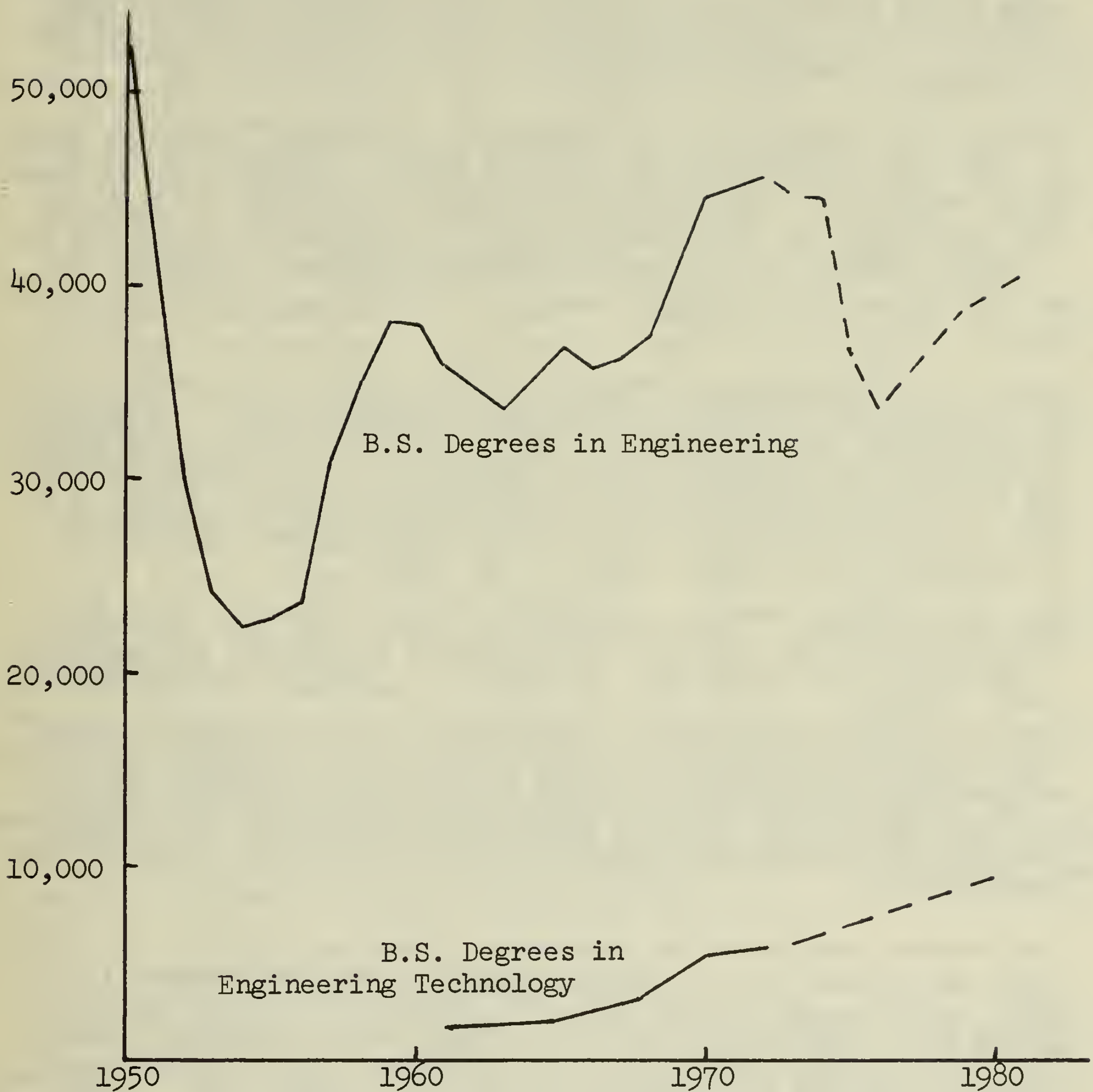
Engineering, however, took a very different development as seen in Fig. N.1 which is based on Ref. 85. Contrary to the rapid growth of higher education in general, the number of bachelor's degrees in engineering decreased and stagnated for a decade from 1959 to 1968 and finally reached a modest peak in the early 1970s -- just when a general recession started. This resulted again in a sharp decrease so that in 1976 the number of engineering bachelor's degrees will be 10% less than in 1959. In 1950 engineering bachelor's degrees represented 12% of all bachelor's degrees, in 1970 less than 6%.

The role of graduate education is indicated by data from the U.S. Office of Education as contained in Ref. 85. Master's degrees in engineering as a percentage of bachelor's degrees in engineering amounted to 19% in 1960 and grew steadily to 36% in 1972. Doctor's degrees in engineering, again expressed as a percentage of bachelor's degrees in engineering, grew steadily from 2% in 1960 to 8.4% in 1972.

The regressive trend in the number of engineering students as shown in Fig. N.1 -- completely contrary to other fields of higher education -- calls for a thoughtful appraisal and we may begin with some considerations about supply and demand.

To arrive at the yearly supply of engineering graduates actually available for employment, Ref. 85 reduces the numbers from the top curve in Fig. N.1. This takes into account degrees awarded to foreign nationals and career military officers, engineering graduates who go directly into non-engineering careers, and adjustments for temporary delays in entering the labor market because of graduate study, etc. It amounts to a reduction by approximately 10%.

The actual working force of engineers is not easily estimated (Refs. 86 and 87). All surveys start from statistical data as enumerated on the basis of householders interviewed by the Bureau of the Census. These data include much quasi-engineering, possibly the maintenance "engineer" of an apartment house, and may exclude engineering graduates who are reported as teachers, managers, salesmen, etc. The data of Ref. 87 have been updated by the Engineering Manpower Commission, based on the occupation as reported in the 1970 census and on education as reported in the 1972



B.S. DEGREES AWARDED IN U.S. IN
ENGINEERING AND ENGINEERING TECHNOLOGY

FIG. N. 1

Note: Forecasts until 1976 are based on present enrollments.

post-censal Professional, Technical and Scientific Manpower Survey. The result is a total of 1,242,500 engaged in engineering occupations, with 585,200 holding their highest degree in engineering, 180,000 holding their highest degree in other fields, and 476,500 holding less than a B.S. degree.

A projection about the yearly demand for engineers has to be based on this type of figures with the additional consideration of three major components: replacement, transfer, and growth -- with the last two involving new uncertainties. Corresponding estimates for the yearly demand vary. The Engineering Manpower Commission in Ref. 88 shows an estimated demand for 48,000 engineers in the mid-1970s.

The staggering discrepancy between the yearly supply of engineers and the demand for them is astounding and bewildering. A comparison between the estimated yearly demand for 48,000 engineers with the actual numbers available for employment as shown in Fig. N.1 indicates a deficiency of about 40%. Engineering technologists will have to fill a large part of this gap.

The implications of these figures are clear. We live in a world of expanding technology and, unless these statistics are fundamentally wrong, we are facing a shortage of engineers who are able to cope with this technology. This happens in the country of highest technological development. Obviously the technological leadership will shift toward those countries where no such shortage exists. They will be able to provide engineers for underdeveloped countries and usually international trade and exports will be determined by these trends.

The reasons underlying the tendency of American youth to shy away from engineering are not quite evident. The trend started in 1956, as evidenced in the change of slope between 1959 and 1960 in the B.S. curve of Fig. N.1, four years after freshmen entered college. Neither anti-technology sentiments nor social unrest can serve as an explanation because they played a role only much later. Even now, one and a half decades after the beginning of this trend, no consensus of opinions about its causes has been reached.

For our purposes it may do well to approach this problem from a realistic viewpoint. Engineering requires a most exacting sequence of studies, offers much hard work with generally slow professional advancement, allows only few of its practitioners to become more than a small cog in a big machine, demands life-long studies to combat the threat of becoming obsolescent, and finally presents the discouraging specter of becoming "old" at an age when people have just properly matured in other professions. How many a promising youthful mind, starting out to build a better world, winds up in a deadly routine and monotony ! Students began to realize in the wake of the 1955 Grinter Report (Ref. 18) that engineering studies meant more mathematics and fewer applications. It appears that in the late 1950s, with the growth of affluence, an increasing number of students began to

make a critical comparison between required effort and prospective reward. They sensed how much easier it was to gain status and material goods following a non-engineering route. The fields of economics, management, and business administration promised a more direct and less painful way to the upper levels of decision-making and social recognition. Perhaps it was partly that the puritan spirit of hard work toward gradual achievement had lost some of its halo, but most likely it was plain and solid reasoning which made students decide against engineering. The pastures were greener and the chances for self-development were better in other fields.

If this interpretation is correct, remedial action along the lines presented in Appendix I may help to change the situation. It would be a change not in the direction toward an easier life for the engineer -- the demands on him are too high and the need for life-long study is too obvious -- but in the direction toward professional recognition and a higher level of responsibility which he did not have as long as he was just an engineering specialist. This professional recognition can come only when the engineer is educated to be a true professional in the sense discussed in Appendix I. With this kind of ecuation he is equipped to assume leading positions of many kinds throughout a technological world. Without it he would be not more than a toady of others who are making the decisions.

This is again the basic difference between the traditional concept of the engineering specialist and the expanding concept of the engineer as the designer and decision-maker under complex conditions. Perhaps the young generation began to weigh the traditional concept more critically than the older generation had done and traditional engineering education was found wanting.

N.3 Aspects of Engineering Technology

While engineering enrollments have been stagnating, enrollments in 4-year engineering technology curricula have shown an amazing growth. The numbers of bachelor's degrees in engineering technology, as reported by the U. S. Office of Education and shown in Ref. 85, are indicated in the bottom curve of Fig. N.1. In 1961 they amounted to 5% of the engineering bachelor's degrees, rose to 10% in 1969, and are expected to rise to 25% around 1980.

Developments in this field are contained in the Engineering Technology Education Study, Ref. 89. Further information on curricula and ECPD accreditation is given in Ref. 31. A detailed consideration of these developments is beyond the scope of the present investigation but some basic aspects are quite relevant.

First of all, the growth of engineering technology enrollments at a time when engineering enrollments floundered, gives much food for thought. Engineering technology curricula fulfill a need for the practical sides of engineering while engineering curricula have been directed increasingly toward research aspects of engineering. It appears that the significance of the practical aspects has not been properly appreciated at most universities.

Secondly, the development of engineering technology curricula makes it necessary to take a fresh look at the total picture. Scientist, engineer, technologist, technician, and skilled worker cover a wide spectrum from abstract thinking to practical doing. All of them form a team rather than a hierarchy. Excellence in the chosen field is the criterion and results in pride of craftsmanship for the skilled employee, sense of service for the professional, intellectual adventure for the scientist.

Scientist	Engineer	Technologist	Technician	Skilled Craftsman
observes natural phenomena and derives laws of nature	conceives means to control forces of nature and apply them to human needs	is concerned with practical ways to translate concepts into hardware	prepares setups and carries out technical tasks in testing and production	has practical skills and special aptitudes required for manufacturing

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Each of these groups has a different function and requires a different education or training. When the student enters the university and even when he obtains his bachelor's degree, he is frequently still unprepared to visualize his future career. Especially in the boundary region between engineering technology and engineering, he usually finds out only from experience whether he is better suited for the purely technical aspects of design which form the core of engineering technology or for the many non-technical considerations of a large system frequently connected with engineering in general. The solution for this dilemma has to be found in mobility between adjacent groups, facilitated by continuing education. An engineering graduate who becomes interested in computer graphics, for instance, will need additional studies in descriptive geometry and computer programming; an engineering technology graduate who grows into a job with broader responsibilities needs correspondingly more education in other fields. Neither engineering nor engineering technology curricula can give more than a solid foundation, each based on a different viewpoint. The flexibility required by the varying circumstances of a lifetime can be provided by continuing education.

Basically this has been recognized by industry. Usually not much initial difference is made whether a recent graduate is a bachelor from an engineering or engineering technology curriculum and it depends on the individual how he develops. Engineering curricula have to prepare the B.S. to be viable under these circumstances.

N.4 Aerospace Aspects

A breakdown of enrollments, degrees, and faculties in ECPD-accredited aerospace engineering programs for 1972 is given in Appendix D. It

should be kept in mind, however, that the early 1970s were a time of rapid change in enrollments. Economic recession, fading out of the Apollo moon program, cutbacks in advanced technology due to the cost of the Vietnam War, and cancellation of the supersonic transport program coincided with a wave of anti-technology and with strong sentiments against the military-industrial complex.

Aerospace was affected most severely by this crisis. Approximately 90,000 aerospace-related engineers and scientists were laid off within about three years after two decades of expansion (Ref. 90). The aerospace industry acquired an unhealthy reputation of boom-and-bust.

The precipitous drop of enrollments in aersopace curricula can be seen from the following figures obtained from the Engineering Manpower Commission of the Engineers Joint Council and from Ref. 91: The total aerospace enrollment in the freshman year in the U. S. declined from 3,235 in 1968, to 3,213 in 1969, 2,851 in 1970, 1,407 in 1971, and 1,028 in 1972, i.e., down to 32%. This compares with a drop in overall engineering freshman enrollment from 77,484 in 1968 to 52,100 in 1972, i.e., down to 68% (Ref. 67). The figures indicate how serious the situation is for aerospace curricula.

A word of caution should be added regarding these figures. They are applicable for the purpose of comparison as used above because they are obtained by consistent methods and always refer to the fall of the respective year. As absolute values, however, they must be qualified due to the influences of attrition, transfers, and merged departments. Particularly the high attrition rate during the freshman year and the number of subsequent transfers from 2-year junior colleges deserve careful evaluation.

The severity of the situation in aerospace is, of course, generally recognized but the consequences are not yet quite visible. Predictions regarding future demand in aerospace engineering are unreliable because they depend on too many parameters. It is a situation full of uncertainties, not unlike a typical design problem.

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A brief review of recent developments in engineering education leads to basic reflections about the importance of design education. Aircraft design is singled out as a field where demands on design are particularly high and urgent. Basic needs are determined. Additional challenges posed by engineering technology, continuing studies, liberal-technical education, and new concepts of professionalism are discussed. An overall perspective is developed which foresees a dynamic evolutionary process and indicates that much initiative should originate on the faculty level while guidance should be provided on a policy-making level.

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